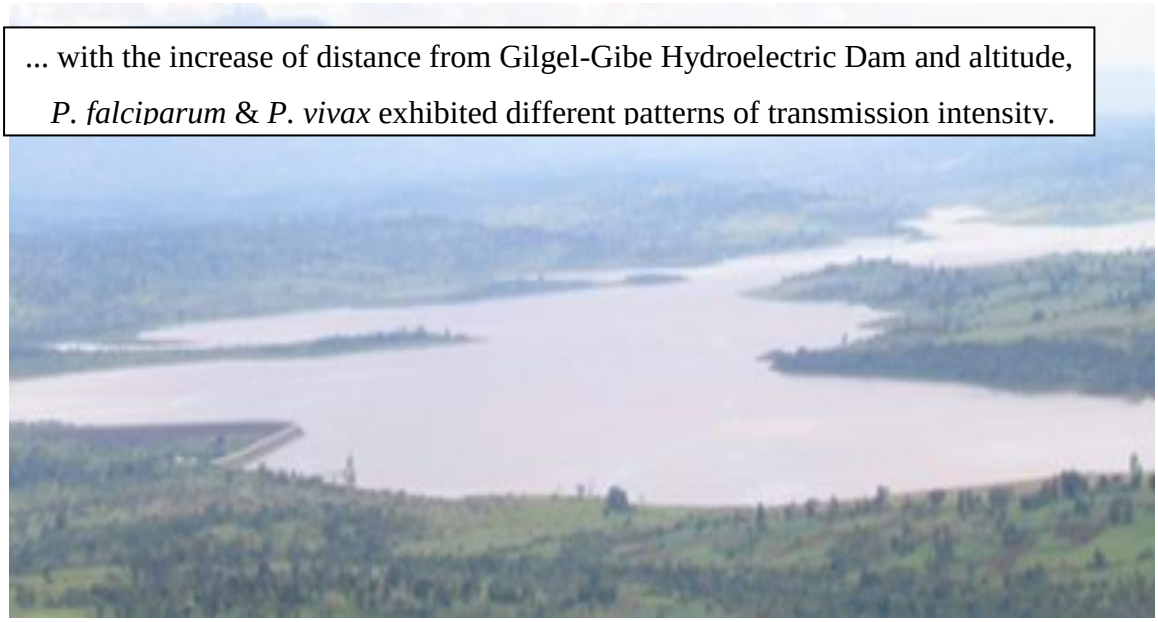
ANALYSIS OF SPATIOTEMPORAL DYNAMICS AND ASSOCIATED FACTORS OF MALARIA: A COMPARATIVE STUDY AROUND GILGEL-GIBE HYDROELECTRIC DAM AND CONTROL VILLAGES, JIMMA ZONE, SOUTHWEST ETHIOPIA

LELISA SENA DADI

... with the increase of distance from Gilgel-Gibe Hydroelectric Dam and altitude, *P. falciparum* & *P. vivax* exhibited different patterns of transmission intensity.



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A DISSERTATION SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES OF ADDIS ABABA UNIVERSITY IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY (PhD) IN PUBLIC HEALTH

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Chair Person , Examining board	Date
Supervisor (Primary)	Date
Supervisor (Secondary)	Date
External examiner	Date
Internal examiner	Date
Internal examiner	Date

Dedication

This dissertation is dedicated to human lives affected by malaria.

List of original papers

I. Sena L, Deressa W and Ali A. **Analysis of trend of malaria prevalence in south-west Ethiopia: a retrospective comparative study** Malar J. 2014, 13:188
DOI: 10.1186/1475-2875-13-188

II. Sena L, Deressa W and Ali **A Dynamics of *Plasmodium falciparum* and *Plasmodium vivax* in a micro-ecological setting, southwest Ethiopia: Effects of altitude and proximity to a dam** BMC Infect Dis. 2014, 14: 625

III. Sena L, Deressa W and Ali A. **Correlation of climate variability and malaria: a retrospective comparative study, southwest Ethiopia** Ethiop. J. Health Sci. Vol. 25 No 2 (in production process)

IV. Sena L, Deressa A and Ali A. **Predictors of long-lasting insecticide-treated bed net ownership and utilization: evidence from community-based cross-sectional comparative study, Southwest Ethiopia** Malar J. 2013, **12**:406 DOI: 10.1186/1475-2875-12-406

V. Sena L, Deressa A and Ali A. **Prevalence of malaria in communities where 'District-based Model' and 'Community-based Model' of indoor residual spray applied** (Compiled in manuscript).

Acronyms and Abbreviations

ANVR	African Network on Vector Resistance
AR	Attributable Risk
C. I.	Confidence Interval
CSA	Central Statistical Agency
DDT	Dichloro**d**iphenyl**t**richloroethane
DHS	Demographic and Health Surveys
DIC	Deviance Information Criterion
DSS	Demographic Surveillance System
ECA	Economic Commissions for Africa
ETB	Ethiopian Birr
FMOH	Federal Ministry of Health of Ethiopia
GG HDSS	Gilgel-Gibe Health and Demographic Surveillance System
GGFRC	Gilgel-Gibe Field Research Center
GGHD	Gilgel-Gibe Hydroelectric Dam
GIS	Geographic Information System
GPS	Geographic Positioning System
HC	Health center
HH	Household
ID	Identification
IDC-10	International statistical classification of diseases and related health problems, 10^{th} revision
IRS	Indoor Residual Spray
ITNs	Insecticide Treated Bed Nets
JU-IHSR	Jimma University Institute of Health Sciences Research
LLINS	Long lasting insecticidal nets
masl	meters above sea level
NDVI	Normalized Difference Vegetation Index
NDVI	Normalized Difference Vegetation Index
PCR	Polymerase Chain Reaction

P. f.	*Plasmodium falciparum*
PHCUs	Primary Health Care Units
P.v.	*Plasmodium vivax*
RBM	Roll Back Malaria
RRI	Incidence rate ratio
S. E.	Standard Error
s.l.	Sensu lato
SM.	Mixed species (P. f. and P. v.)
s.s	sensu stricto
SES	Socioeconomic status
SSA	Sub-Saharan Africa
TDR	Tropical Diseases Research
TIR	Test Incident Report
UNAID	United Nations Agency for International Development
UN	United Nations
VA	Verbal Autopsy
WHO	World Health Organization

Glossary

Asymptomatic malaria is laboratory confirmation (by microscopy or immuno-diagnostic test) of parasitaemia in a person with no recent history of signs and/or symptoms of malaria.

Bed net*:* Any insect nets used for sleeping either treated or untreated with insecticide

Community-based Model' of indoor residual spray is indoor residual spray modality where by most of the spray activities are lead by health extension workers who had been recruited from the community and carried out the spray together with individuals recruited from the same community with a minimal technical assistance from the district health office**.**

Confirmed severe malaria is a person requiring hospitalization for symptoms and/or signs of severe malaria, who receives antimalarial treatment, with laboratory confirmation of diagnosis **(in areas with access to laboratory-based diagnosis)**.

Confirmed uncomplicated malaria is a patient with symptoms and/or signs of uncomplicated malaria, who receives antimalarial treatment, with laboratory confirmation of diagnosis (**In areas without access to laboratory-based diagnosis**).

District-based Model of indoor residual spray: it is indoor residual spray modality whereby district health office plans and implements the indoor residual spray with technical and operational inputs from regional, zonal, and central health offices and majority of the technical preparation and management takes place at district level; and a team of spray operators (16-20 individuals) moves from district to the community with all the necessary equipment and supplies.

Geographical Information Systems (GIS) is a computer system relevant to the administration and analysis of spatial data.

Household: domestic units consisting of the members of a family who live together and share meals, including non relatives such as maids.

Insecticide Treated Bed Nets Possession: Households who own intact ITNs of any kind

Insecticide Treated Bed Nets Utilization: Perception of respondents that ITNs prevents from mosquito bite and hang intact ITNs at sleeping area or on bed during the survey time and intact ITNs

Insecticide Treated Bed Net*:* Either a long-lasting net that does not require re-treatment or a pre-treated net obtained within the last 12 months inclusive, or a net that has been soaked with insecticide within the last 12 months inclusive.

Malaria control**:** reducing the burden of malaria to a level at which it is no longer a public health problem.

Probable malaria death is death of a patient who has been diagnosed with probable severe malaria (**in areas without access to laboratory-based diagnosis**).

Probable severe malaria case is a patient requiring hospitalization for symptoms and/or signs of severe malaria, who receives anti-malarial treatment (**in areas without access to laboratory-based diagnosis**).

Probable uncomplicated malaria case is a patient with symptoms and/or signs of uncomplicated malaria, who receives anti-malarial treatment (**in areas without access to laboratory-based diagnosis**).

Risk factors of malaria are behaviors/conditions of individuals, household members, or environmental characteristics that predispose/expose the members of a community to malaria.

Spatiotemporal dynamics of malaria is change of malaria distribution/ transmission by place and time period. This refers to clusters of malaria cases by place and time (excess of cases that are close in both space and time), by *Plasmodium* species and by persons affected.

Trend of malaria is malaria transmission pattern over time (months, season and years) as explained by plasmodia species composition change/stable, number of cases increment/decrement or stable during the time frame considered.

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Abstract

Background

Analysis of spatiotemporal dynamics of malaria data of health care systems along with climatic variables and assessment of the intervention tools provides important insights into the changing malaria situation, which might guide adjustments of malaria program activities and priorities of malaria research topics. The objectives of this study were to compare trends of malaria, to analyze spatiotemporal dynamics of malaria in the Gilgel Gibe Hydroelectric dam (GGHD) site, to examine the role of climatic variables on malaria, to determine possession and utilization of long lasting insecticidal nets (LLINs/ITNs), and to evaluate the prevalence of malaria around GGHD and a control site.

Materials and methods

Records of malaria cases over eight years period in health facilities of the two sites were reviewed along climatic variables. Malaria episode and meteorological data were registered on excel spreadsheet separately. Summary of the data were exported to SPSS version 20 for Windows and linked together using unique identifiers. Prevalence of malaria was analyzed and described by person, place and time using line graphs. Spearman correlation coefficient was analyzed to explore the correlation between climatic variables and malaria episodes. Malaria episodes of the two sites was compared using odds ratios.

Spatial analysis was carried out by linking malaria episodes data of GGHD site with the Gilgel Gibe Health and Demographic System (GGHD-HDSS) data that have been geo-referenced. Poisson regression model was applied to estimate odds ratios of the malaria episodes among buffer zones and altitude ranges of the site using the STATA statistical software version 12. A household survey was conducted during peak malaria transmission season to assess possession and utilization of LLINS by households. Similarly, blood survey was conducted during the same season using rapid diagnostic test (RDT). Both data of the household and blood surveys were entered into EpiData entry II database and exported to SPSS version 20 for Windows for analysis. Binary and multinomial logistic regressions were employed to identify predictors of LLIN ownership and utilization.

Results

Two-third of the 163,918 registered malaria episodes were slide/RDT confirmed cases. Plasmodium falciparum (P. falciparum) and Plasmodium vivax (P. vivax) accounted for 54.6% (60.4% in GGHD site and 52.3% in control site) and 41.6% (33.6 in GGHD site and 44.7% in control site), the rest (3.8%) was mixed species infections. P. falciparum and P. vivax were twice and nearly trice times more likely to occur in the control site compared to GGHD site. Several peaks of malaria transmission seasons were noted in the control site whereas only two small one main transmission peaks were observed in the GGHD. The probabilities of infections by both P. falciparum and P. vivax were high in the control site than in the GGHD site in all age categories. Children from 10 to 14 years were the most affected followed by children below the age of 10 years.

In the GGHD site, 45.0% of the P. falciparum episodes were registered within one-kilometer radius of the Dam. Yet, as distance increases from the GGHD, the odds of P. falciparum occurrence increases significantly up to five kms, when adjusted for population density. Positive and significant correlation between P. falciparum occurrence and altitude was also noted. Again; as the distances from the GGHD increases, the occurrence of P. vivax increases. On the other hand, increasing altitude was negatively and significantly associated with the occurrence of P. vivax malaria. At the GGHD site, moderate correlations were seen at months 2 and 3 lags with both rainfall and relative humidity. There were only weak positive correlations at month 4 for rainfall and months 2 through 4 for relative humidity at the control site.

The overall coverage of LLINS was 56.6% (in GGHD site and control site). Higher number of HHs from GGHD site reported to have at least one LLINS (OR = 2.2 & P < 0.001) whereas higher number of HHs from control site reported to have two or more LLINS (OR = 2.1 & P < 0.001). Factors that independently affect the possession and utilization of LLINS were found to be age of HH heads, HH RWI, accessibility to all weather roads, proximity to health facilities. From the total 2269-screened individuals, only 17 were tested positive for malaria. Since all the cases were from District based site, the prevalence in the site was 1.4% whereas it was zero in the site where the Community-based IRS was applied.

Conclusions

Malaria prevalence was higher in the control than the GGHD site. The present finding did not show evidence of excess malaria burden in the GGHD over the study period. Yet, the fact that the trend of malaria prevalence in GGHD exhibited increasing slope, the identification of malaria cases near GGHD and significantly high prevalence of P. falciparum near the GGHD imply the possible role of the dam in maintaining malaria hot spot. Weak/absence of linear correlation between malaria episodes and climatic variables does not prove absence of the association between malaria and climate variables. The blood survey positivity rate was very low suggesting the need for additional study before concluding whether the community based model of IRS works effectively to control malaria. In GGHD site, irrespective of the low prevalence noticed, the transmission of malaria might have been maintained associated with the Dam.

Recommendations

- *Regarding the increment of P. falciparum with altitude and that of P. vivax with distance from reservoir of dams, further exploration is needed.*
- *There is a need to consider additional factors such as normalized difference vegetation index and the physico-chemical nature of the breeding sites of mosquitoes.*
- *Attention needs to be given to the poor, distant and inaccessible households in the efforts of malaria intervention programmes. Well-tailored information, education and communication (IEC) is needed to address the problem of non-users of LLINs.*
- *Applicability of the community-based model of IRS need to be further explored in different localities to fully replace the district based model of IRS in the future.*
- *Patient records at health facilities should include family identity (ID) so that spatial analysis of diseases can be carried out by linking cases history to the family.*

Key words: *Climatic variables, Ethiopia, Gilgel Gibe, hydroelectric dam, malaria trend, spatiotemporal dynamics, bed nets*

1. Introduction

1.1. Background

Malaria is a vector-borne disease caused by protozoan parasites belonging to the genus Plasmodium and transmitted by the bite of infected female *Anopheles species* mosquitoes; about 60 species of the genus *Anopheles* can transmit malaria (1, 2). Until recently, five species of *Plasmodium*, namely: *P. vivax, P. falciparum, P. ovale (*two sub species*: P. ovale curtisi and P. ovale wallikeri), P. malariae* and *P. knowlesi* are known to cause human disease (3-7). The conditions of the parasite, vector and the human host are characterized by different factors, which are highlighted here.

The transmission of malaria involves a complex interplay among the parasite, vector and host. It is influenced by behavior, socioeconomic status and demographic factors of the human host and public health control measures (8-10). The presence and abundance of the vectors depend on, among other things, both biotic and abiotic environmental factors (11-13), which are usually affected in turn by seasonal variations (14-17) and micro-ecology of the mosquitoes (18-20). The pattern of malaria transmission is influenced also by the bionomics of the vector mosquitoes (21). Biting and resting behaviors of mosquitoes play also decisive role in the dynamics of malaria transmission (22-24). Climatic factors can determine both the parasite and the vectors of malaria in many ways: the extrinsic development of *Plasmodium* species are highly affected by temperature (25) and optimum climatic variables mainly temperature, humidity and precipitation are needed for the proliferation of *Anopheles* mosquitoes (26, 27) to sustain malaria transmission.

Additionally, human prevention and control behavior, socioeconomic and demographic conditions can significantly affect the dynamics of the disease (28-30). Moreover, anthropogenic disruption of the natural equilibrium of environment inevitably modifies the malaria transmission dynamics (31, 32). In this regard, the present study has assessed the spatiotemporal dynamics of malaria and associated factors. In particular, trends of malaria were analyzed and compared for the two sites; climatic variables have been included in the analysis to see whether the climatic variables play any important role in the pattern of malaria prevalence in those sites. Main malaria prevention and control tools status of the area along related socioeconomic have been assessed as well.

1.2. Statement of the problem

The risks of morbidity and mortality associated with malaria are characterized by different factors including spatial and temporal variations(33). The spatial component of health data can play a crucial role in helping explain variability in environmental hazards, population at risk, demographic and socioeconomic profiles, and other relevant characteristics pertaining to malaria (34, 35). In this sense, geographic space varies uniquely in different locations and at different times and creates unique places in which people live and work (36, 37). Moreover, environmental modification as the result of water project development such as dams and irrigations continue to be planed, constructed and operated to meet human needs, which can have role in facilitating transmission dynamics of malaria (36, 38).

However, a cross-sectional study conducted in Uganda failed to show the relationship between malaria prevalence and environmental as well as socio-economic variables (39) and use of disaggregated data and panel data were recommended to identify factors that influence malaria prevalence. Again, in WHO sub-regions 1 and 2 (African Regional Office and countries in other 3 WHO sub-region where infant and adult mortality rates are higher) that have 87.9% of the current global malaria burden, only 1.1% of population is estimated to live near large dams and irrigation schemes (36). So, it has been emphasized that whether an individual water project triggers an increase in malaria transmission depends on the contextual determinants of malaria, including the epidemiologic setting, socioeconomic factors, vector management, and health seeking behavior (36).

Studies also showed that the *Plasmodium* species composition and the number of malaria cases vary over time (38, 40-42) due to different factors, such as previous weather conditions (43) or intervention measures (44). A retrospective study revealed that there was decrement of *P. vivax,* whereas *P. falciparum* increased over five years period in a General Hospital in Ethiopia (45). Thus, similar study was recommended to assess situations of other areas in the country. Temporal analysis of relevant malaria data of health care system provides essential information needed to measure success and failure of national malaria programs and identify the remaining malaria hot spots. It also gives important insights into the changing malaria situation, which might guide adjustments of malaria control program activities and the prioritization of the malaria research agenda (46, 47). Therefore, the changing malaria situation requires updating spatial and temporal descriptions of an endemic locality (48).

To assess the contribution made by operational intervention and effect of environmental factors, a clear knowledge about the dynamics of malaria in a particular area is important so that prevention and management strategies can be planned in a more effective manner (49). Since malaria transmission intensity varies geographically, the distribution of cases and subsequent morbidity rate may exhibit systematic spatial variation (50). Thus, a systematic approach to geographical variation has been recommended as both economic and epidemiological factors vary greatly in different settings where aggregate data are of less value to assist policy-makers (51).

Studies on micro-epidemiological level addressing the spatial and temporal dynamics of malaria transmission are scarce in Ethiopia in spite of the ongoing environmental modifications due to water projects, like hydroelectric dams. Therefore, the current study intended to assess both spatiotemporal dynamics of malaria and the factors that affect the dynamics around Gilgel-Gibe Hydroelectric Dam (GGHD) and a control area. In doing so, prevalence of malaria over an eight year period along with climatic variables (rainfall, temperature and relative humidity), spatial distribution of malaria cases around GGHD and utilization of main malaria prevention and control interventions (LLINS and IRS) have been studied. Factors related to possession and utilization of LLINS were analyzed.

1.3. Rationale of the study

Quantitative description of the spatiotemporal dynamics of malaria has practical implications for the development of operational malaria control and efficient allocation of resources (52, 53). Spatial and temporal analysis of malaria may help identify high-risk areas, sources of diseases, and high-risk populations. Assessment of malaria spatiotemporal dynamics can also play an important role in evaluating changes in malaria transmission over time and allocating resources to control malaria, especially in high or persistent local malaria transmission areas (54).

Currently, Ethiopia is undertaking construction of large hydroelectric dams (55, 56) and irrigation schemes of different scales (57-59) as part of developmental activities. This in turn can have impact on vector borne diseases, including malaria. Due to human imposed environmental degradation, risk of malaria has been predicted to increase in East Africa (60). On the other hand, well designed water projects, like irrigation dams are thought to be economically beneficial to the dam vicinity residents in the short term and enable the community to strengthen the disease control program to overcome the medium and long term adverse health effects (28, 61). However, the extent of health impact of hydroelectric dams on local community closer to such dams is inadequately studied. In this regard, it is of paramount importance to document the consequences of such man made water body for evidence-based intervention.

This study has been undertaken to integrate information from environmental variables, socio-economic and socio-demographics, malaria morbidity records of local health service facilities' as well as Plasmodium species data to identify spatiotemporal dynamics of malaria since the construction of GGHD and related risk factors. Hence, possible adverse impact of GGHD on malaria transmission could be assessed in comparison to the control area. Thus, the results of this study are envisaged to enable policy-makers and health planners to implement malaria prevention and control interventions in spatially explicit and locally prevailing conditions.

1.4. Literature Review

A number of factors contribute to the spatiotemporal dynamics of malaria (10). Hence, the burden of malaria and control efforts, the roles socioeconomic factors, development of water projects, climatic variables, and intervention tools such as: long lasting insecticide treated bed nets and IRS are mentioned in relation to malaria dynamics in the subsequent sections.

1.4.1. Burden of malaria and control efforts

Globally, malaria affects the health and wealth of more than three billion people and causes more than a million deaths annually (3, 62). High burden of malaria is the cause and result of poor socioeconomic conditions resulting in vicious cycle of the impact (63-65). Pregnant women and children under 5 years of age are the most vulnerable groups. In adults recurrent bouts of fever as the result of reinfection and super infection reduce labour productivity (66); direct and indirect economic costs of malaria have been estimated to be high (67, 68). It also predisposes people, especially infants and young children to other diseases (69). Malaria impairs school performance and cognitive abilities that continues even after recovery (70, 71). Furthermore, the complications it causes to pregnant women, resulting in miscarriage, maternal deaths due to hemorrhage and anemia, and subsequent sequels from low birth weight and congenital infections of the newborn, growth and mental retardations are some of the burdens malaria poses on human beings (72-74).

The global malaria eradication program during 1950s and 1960s suffered serious setbacks and the disease increased slowly in areas where it had been reduced to low level (10, 75). In an effort to combat the growing threat of malaria, the Roll Back Malaria (RBM) partnership was launched in 1998, with the goal to reduce the burden of malaria by half up to 2010 (76) and halving again by 2015 (76). The United Nations (UN) had also declared the Decade to Roll Back Malaria (2001–2010) in developing countries. Moreover, African heads of States met in Abuja, in 2000 to express their commitment to combating malaria (77, 78).

As the result, there has been substantial reduction of malaria in some countries (48, 79, 80). According to the WHO malaria report of 2010, in the decade from 2000 to 2009, out of 98 malaria endemic countries 42 (42.9%) of them reduced malaria cases by more than 50%; however, in 49 (50%) countries, including Ethiopia, there was no evidence of malaria cases reduction since 2005 (79). On the

other hand, some studies have indicated substantial decline of malaria cases from sub-Saharan Africa, including Ethiopia due to intensive interventions, particularly scaled-up distribution of ITNs, IRS and use of rapid diagnostic kits at lower level health facilities and prompt treatment of cases (80, 81). The possible reasons for the conflicting reports could be due to relying on different sources of data such as country level aggregated data of health facility reports, which are usually incomplete, or indicator sample surveys that could also miss specific local situations. According to the World Malaria Report of 2014, there have been substantial progresses both in coverage of intervention tools and, consequently, reduction in malaria related morbidity and mortality globally and, especially in the WHO African Region (82).

In Ethiopia, the occurrences of epidemics of malaria have been documented since the 1930s and 1940s. The most devastating epidemic was that of 1958 which resulted in an estimated three million cases and 150,000 deaths (83, 84). Until recently, malaria has been the leading cause of morbidity and mortality in Ethiopia, accounting for over five million cases and thousands of deaths annually (80, 85). The two peak seasonal transmissions of malaria occur during September to December and March to May (80, 86). Present strategies involve early diagnosing and treating infected individuals and reducing human-mosquito contact rates through vector control efforts (87). Dichloro**d**iphenyl**t**richloroethane (DDT) has been the insecticide of choice for indoor residual spray (IRS) for about four decades in Ethiopia. In some areas where the *An. arabiensis* has developed resistance to DDT, Malathion is applied as an alternative insecticide. Anti-larval measures are considered where IRS is impractical around urban areas or when there are limited numbers of breeding places. The Malaria Control Program scaled up also the distribution of ITNs to areas where transmission season exceed three months (80, 88).

1.4.2. Socioeconomic and behavioral determinants

Socioeconomic and behavioral factors can substantially affect malaria dynamics (10, 89-92). At a macro level, there is clear evidence that the burden of malaria is greatest among the poorest countries of the world, especially those in sub-Saharan Africa. However, studies, using assets as a proxy for socioeconomic status (SES), have failed to establish a clear relationship between property ownership and the incidence of febrile episodes as a proxy for malaria (51). Evidence concerning malaria incidence and occupation is also mixed (93, 94).

Similarly, some of the empirical studies done in different countries, in fact involving different methodologies, reported controversial findings (95). For instance, a study done in Central Vietnam involving complete community-based cross-sectional showed that the most important risk factor for malaria was the wealth category, the wealthiest group being much less infected. Among the wealthiest category, forest activity and bed net use were the most determinant risk factors for malaria, while in the lower and medium wealth category; insecticide treated nets were most important (95), implying that the importance different factors depend on local contexts.

Another study done in India using five years records of primary health care found that magnitude of malaria was three times more in the underdeveloped community compared to developed community (96). This study did not consider whether the two study areas have similar features such as environmental conditions, which can make significant differences in the dynamics of malaria transmission. Again, a study done in three major regions of Ethiopia showed that the risk of malaria decreased as household wealth index increased (97). Similarly, a study done in Tanzania showed that households of higher wealth index were found to be infected less compared to those middle and lower wealth index households (98).

An other survey conducted on primary care givers or household heads showed that self diagnosis was practiced more by poorer households, while the least poor used the patent medicine dealers and community health workers less often for diagnosis of malaria (99). The factors that encourage people to use services in Bamako Initiative program health centers were availability of good services, proximity of the centers to the homes and polite health workers.

Again, a study has revealed that malaria risk was significantly higher among children who lived in households with lower economic or education levels, near the hydrographic network, in sparsely built-up areas, in irregularly built areas, who did not use a bed net (100). An interview based community survey carried out during the high malaria transmission season in India revealed that majority of respondents sought some sort of treatment and the most common reason (66.9%) for choosing a provider was proximity (101). Interviews with the providers also indicated that patients' lack of trust in community volunteers providing treatment led to inappropriate treatment-seeking from the less quali-

fied providers. The investigators have suggested the need for continuous and rigorous impact evaluations of the program to make necessary modifications, scale up and to prevent drug resistance.

A study conducted in Malawi on caregivers and health workers, using focus group discussions, revealed that despite high knowledge of malaria, prompt treatment and health-seeking behavior were poor, with the majority of children first being managed at home with treatment regimens other than effective anti-malarial drugs (102). According to that study, traditional beliefs about causes of fever, unavailability of anti-malarial drugs within the community, barriers to accessing the formal health care system, and trust in traditional medicine were all associated with delays in seeking appropriate treatment for fever.

Another similar study done in Sudan has indicated that regardless of high score of mothers' knowledge and recognition of fever/malaria, mothers usually started care at home and, within an average of three days, they shift to health workers if there was no response (103). According to that study, the main health-seeking behavior was to consult the nearest health facility or health personnel together with using traditional medicine or herbs. The choice between available options was determined by the availability of health facilities, user fees, satisfaction with services, difficulty to reach facilities and belief in traditional medicine. A qualitative study conducted in Burkina-Faso showed that health care-seeking behavior and choice of provider are strongly influenced by local concepts of illness (104).

Saeed and Ahmed (105) documented also that the occurrence of malaria death among households of internally displaced people was significantly associated with poor knowledge about malaria, but unusually with head of households who are educated better. Again, poor treatment-seeking behaviour and poor attitudes towards malaria were not associated with higher mortality. However, mortality was significantly higher among households obtaining water by cart than from a well. In that study, the fact that the number of deaths were small relative to number of households, 81 deaths in 856 households, might have masked true associations between malaria deaths and socio-demographic characteristics of study participants.

On the other hand, studies conducted in Yemen (106) and Uganda (107) failed to show malaria risk difference due to socioeconomic factors. Another community based survey conducted in Nigeria indicated that more occurrence of malaria was reported amongst children and other adult household members who were in a better SES groups compared to the in worse SES groups (108), better-off SES quartile and urban dwellers owned more mosquito nets. A study done in Mozambique showed that while overall net ownership in the sample was low, the evidence did not suggest that poorer households are less likely to own bed nets, when controlling for covariates, nor does the likelihood of receiving a free net depend on socioeconomic status. Formal schooling and market knowledge seem to indicate higher average willingness to pay, while use of alternate methods for malaria prevention, and receipt of IRS are found to decrease demand for bed nets(109). The inconsistencies of different findings in relation to SES status and risk of malaria could be due to local contexts.

1.4.3. Dynamics of malaria and development of water projects

Anthropogenic interference of malaria prone environment due to construction of dams, roads, and industrial and residential centers, can result in disruption of the terrain, allowing increased mosquito breeding; hence, inevitably modifies the dynamics of malaria transmissions (110) In this regard, studies reported different findings. A study conducted in Peru showed significant spatial cluster of both *P. vivax* and *P. falciparum* each year (54). The relative risks of those clusters were higher for *P. falciparum* than for *P. vivax.* The attributable risk (AR) was higher for *P. falciparum* (51%) than for *P. vivax* (30%).

Similarly, a cross-sectional study conducted in Vanuatu, indicated spatial autocorrelation of malaria prevalence and showed significant association with elevation and distance to coastline for *P. vivax* and *P. falciparum* (111). This study used different statistical models and considered elevation as well as inclusion of environmental variables. It showed also the need to consider different predictors for the plasmodia species dynamicity with respect to distance and altitude. In fact, this later point needs to be assessed in different settings whether it holds true everywhere. Moreover, this study did not consider time trend. A study done in India showed also that in spite of the intensive insecticide based control areas adjacent to trunk of large irrigation was characterized by increased risk of *P. vivax* malaria for a decade (112).

Also, a study conducted in Afghanistan (113) highlighted that vegetation index, as consequence of irrigation, was the main predicator of malaria followed by surface temperature in the country; however, precipitation was not shown to be important predictor of malaria. A study done in Ghana reported that the odds of self-reported malaria was significantly higher among women living within a kilometer distance of irrigated urban agriculture compared to those women living near an irrigation source (114). Socioeconomic and demographic characteristics of the participants were found to be associated with self-reported malaria.

However, other studies failed to show an increment of malaria risk due to proximity to water bodies. At large scale, in WHO sub-regions 1 and 2 that have 87.9% of the current global malaria burden, only 1.1% populations are estimated to live near large dams and irrigation schemes So, it has been emphasized that whether an individual water project triggers an increase in malaria transmission depends on the contextual determinants (36). A study done in Somalia has shown that distance from water; precipitation and temperature had no significant association; whereas all the covariates, except distance to water, were significantly associated with parasite prevalence (115). Again, a local study reported that the incidence of malaria among children who live near and far from a dam were not significantly different (116). Furthermore, Hague and colleagues (117) reported that proximity to water source was not risk factor but forest was found to be significant predictor of malaria infection.

A more detail study done in Sri Lanka revealed also that the risk of malaria in irrigated areas was rather lower than in other areas as people engaged in irrigated agriculture were in a better life standard due to better income (118). The study highlighted other ecological and climatic factors that increase the risk of malaria. Another study conducted in India reported also that neither annual parasitic index nor slide positivity rate were increased due to construction of canal system after release of water (119). Yet ,another study (120) implicated the importance of other factors, such malaria epidemiological pattern of malaria before interventions, control measures, migrations, human behavior and local Anopheles bionomics as determinants on malaria dynamics, but not the construction of dams and irrigation canals. A study done in Tanzania revealed also the importance of spatiotemporal consideration at small scales taking into account the agro-ecosystems as malaria transmission intensity can vary even between neighboring villages (121).

A case control study conducted in Kenya revealed that environmental factors, such as living on flat land, living close to forests, and having bushes, but not trees within distance of less than 200 meters from the house, living near channels, in close proximity to maize fields, lack of ceiling in the house, a separate kitchen and having goats in the compound were found to increase the risks of malaria (122). The researchers explained that having a kitchen separate from the sleeping area was strongly associated with increased malaria odds, perhaps because smoke repels vector mosquitoes. In this study; however, absolute elevation was not associated with risk of malaria. They accounted the narrow range (213 meters) of elevation across the study area that might have obscured association.

Another case control study conducted in west Kenya high land found a significant relationship between malaria risk and elevation (30). According to this study, malaria risk decreased with altitude, with significantly fewer cases occurring amongst children living above 1800 meters compared with children living below 1750 meters and decreased risk of malaria was associated with increased distance from the forest fringe and household socio-economic status was lower among the cases than controls. Haque and colleagues also reported that individual age and nearness to fragmented forest were associated with increased malaria prevalence (94).

A study conducted in south Africa highlighted that the risk of malaria was heterogeneous and associated with poor socioeconomic status (123) and malaria hot spots transmission with cluster of higher mosquito exposure was reported from Tanzania, where parasites prevalence rate could detect micro-epidemiological level spatial variations (124). Again a study conducted in Viet Nam indicated that strong spatiotemporal heterogeneity of malaria even after accounting for social and environmental fixed effects (29). Both the Tanzania and Viet Nam studies have highlighted unsatisfactory prediction of malaria based on the probability model of environmental factors. A study from Peru indicated that more spatial heterogeneity was observed in *P. vivax than P. falciparum* and the incidence of the later declined recently across geographical regions, while that of the former had remained relatively steady (125). On the other hand, a study conducted in an urban setting of India reported that distribution of *P. vivax* was random, whereas that of *P. falciparum* was spatially clustered (126).

Some of the studies conducted in Ethiopia pertaining to the effect of micro dams on malaria transmission reported increased risk of malaria as the dams create microclimate changes (elevated minimum ambient temperature), provide cool and humid microhabitats for mosquitoes due to water seepage, saturation of soils and abundant growth of vegetation (127). Clustering of malaria cases by time and space was reported due to micro dam as well (128). Again, study done by Gebreyesus et al (129) indicated that the incidence of malaria in children near the micro dams (within 3 km radius) was seven fold higher than those children who live away from the micro dams. The comparability of the study sites was less articulated, except altitude, to give better information. Moreover, there is paucity of information as to Plasmodim species composition and time trends. Although the increased risk of vector-borne diseases, including malaria have been correlated to dams and small reservoir extensively, the correlation of malaria and hydroelectric dams has been indicated to be weaker (130).

Another study reported also that mean biting rate, mean sporozoite rate and annual entomological inoculation rate were higher in an irrigated sugarcane area compared to traditional and non-irrigated agro-ecosystems (131). Again, study reported by Yewhalaw et al (132) showed that 43% malaria incidence among children who live within 3 km radius of GGHD was attributed to the Dam compared to those who live away from the Dam. This study did not assess trend of malaria over time as it was cross sectional by its design. Furthermore, the effect of altitude can be a confounder as the dam is at lower elevation. A recent local study indicated that malaria prevalence was higher in irrigated villages compared to non-irrigated villages, and mosquito vector abundance varied both with season and between the villages (133). Yeshiwondim et al (33) considered both malaria distribution by time and place. This study has shown that malaria incidence was significantly higher among males and under five children . Significant local clustering of malaria incidence occurs between pairs of villages within 1–10 km distance lags as well (33). This study was not intended for dam effect assessment; rather was limited to assessing spatial clustering, distribution of malaria by person and time. Additionally, another local study revealed that proximity to a dam was associated with an increased risk of malaria, particularly that of *P. falciparum* malaria; whereas *P. vivax* malaria was more prevalent in distant villages (56). Similarly, another study done in the same area revealed that both cases of malaria and abundance of malaria vectors were found to be higher in the community closer to the dam (134).

1.4.4. Dynamics of malaria and climatic variables

Malaria is considered to be an environmental disease. Environmental factors such as changing rainfall patterns and unusual temperature increase can play great rolls in malaria transmission dynamics (75, 85). Brooker et al (135) have indicated that the distribution of malaria is determined by climatic and other geographic factors, which affect mosquito and *Plasmodium* species reproduction. Warm temperatures, heavy rainfall, and high humidity are known to encourage mosquito breeding, longevity and shorten parasite sporogony. *An. gambiae* mosquitoes breed readily in large and small collections of sun-exposed stagnant water (92, 110). .

Changes in temperature, precipitation and humidity that are expected to occur under different climate change scenarios affect the biology and ecology of vectors, which consequently affect the risk of malaria transmission (51, 136-138). If water temperature rises, the larvae take a shorter time to mature and hence, there is a greater capacity to produce more offspring during the transmission period. In warmer climates, adult female mosquitoes digest blood faster and feed more frequently, thus increasing transmission intensity (139, 140). Similarly, malaria parasites complete extrinsic incubation within the female mosquito in a shorter time as temperature rises thereby increasing the proportion of infective vectors (141).

Increased precipitation has the potential to increase the number and quality of breeding sites for vector mosquitoes and the density of vegetation, affecting the availability of resting sites. Cold temperatures induce mortality or slow developmental rates (137), or reduce host-seeking activity. Similarly, rainfall creates habitat for breeding for mosquitoes, and high humidity is necessary for survival of mosquitoes (34, 142). The change of temperature favors mosquitoes development depending on the prevailing local weather conditions (16, 143). A study conducted in Zimbabwe, indicated that annual average temperature, rainfall and vapor pressure were strong positive predictors of increased annual malaria incidence, whereas maximum and minimum temperature had the opposite effects (52). Reid and colleagues documented also that malaria incidence rate was highly correlated with temperature and humidity, but inversely associated with precipitation (144). They explained the negative correlation between malaria incidence and rainfall by the fact that a heavy rainfall can wash the ground and kill the eggs.

According to a study done in Malawi, average temperature and average precipitation were found to be associated with occurrence of malaria at lags of three months (145), but a study conducted in Uganda indicated that rainfall anomaly following El Nino event was associated with increased malaria risk at one month lag (146). A similar study conducted in China reported that climatic factors were correlated with *P. vivax and P. falciparum* at lag of a month (147). A local study done in an urban setting documented that incidence of malaria was significantly and positively associated with maximum and minimum temperatures at lag of a month, whereas rainfall was found to be positively, but weakly correlated at delay of ten weeks (148). Additionally, positive correlation between malaria cases and maximum temperature and rainfall was highlighted by a study conducted in Bangladesh and elevation was also noted as an influential factor (149).

Again, ten-year retrospective trend study done in Jimma Town, Ethiopia and showed not only fluctuation of number of malaria cases, but also changes in species of Plasmodium parasites following climatic variables (150). Another local study that covered eighteen districts and ten years data of monthly malaria morbidity reports has revealed that malaria cases distribution was heterogeneous both spatially, temporally and spatiotemporally (151). Thus, understanding how malaria varies in the community as a result of seasonal or year-to-year changes in environmental factors is important for the planning of national malaria control programs (152)

1.4.5. Insecticide treated bed nets as main malaria prevention tools

Current methods of malaria vector control are highly dependent on pyrethroids, which are the most commonly used compounds for indoor residual spraying (IRS) and the only insecticide class used for insecticide treated nets (ITNs). The widespread use of a single class of insecticides increases the risk that mosquitoes will develop resistance, which could rapidly lead to a major public health problem (79). Apart from resistance, bed nets as a tool for malaria control can have other challenges such as coverage, proper use, reimpregnation, and replacement of old and torn nets (153). Further, consideration of the possible shift of the local malaria epidemiology prompts the need for evaluation of its proper use and effectiveness in protecting malaria to ensure the long-term benefit of this control method (154-156).

Studies conducted in different settings pertaining to ITNs reported different findings regarding its utilization and effectiveness to reduce malaria risks due to various factors. For instance, a study conducted in Bangladeshi Highland indicated that households with less than three bed nets are two times at risk of malaria infection compared to households that had three or more bed nets (117). The study has identified also that 41.4% households with malaria positive cases had more than five household sizes. This implies that distribution of ITNs one or two per households, especially in a rural setting where the household size is large, may not give guarantee to protect family members. It is known that children less than five years of age and pregnant women deserve priority to sleep under bed net. But that study revealed that children were more than four times at risk of malaria compared to adults, (greater than 17 years) although such crude age classification is not epidemiologically plausible.

A study done in Kenya showed that insecticide-treated bed nets have protective effect even for non user compounds in a short distance from user compounds when the coverage among users is fifty percent or more, but doesn't protect when the coverage is less than 25% (157). However, studies done in Equatorial Guinea and Malawi indicated that ITNs did not protect non-user neighbors and its protective potential depends on both intactness and coverage of the ITNs; whereas (158).

A study done in Tanzania, involving both health service records of malaria morbidity, two weeks fever recall survey of households and DSS data of four years (2005-08) indicated that a marked decline of malaria possibly due to better health seeking behavior of community and scaled up ITN intervention (159). Another study conducted in Kenya involving randomized controlled trial has also shown reduction of malaria mortality and severe malaria among less than five years of age children (160).

Furthermore, an eight-years retrospective study carried out in Mali on outpatient consultation records of urban community health centers using logistic regression and trends revealed that the monthly presumptive malaria diagnostic rate for children under five decreased by 66% and, the multi-level analysis related 37% of this decrease to the distribution of bed net and treatment kits initiated in May of 2001 (47). Another cross-sectional study conducted in Eritrea revealed increasing coverage of ITNs (81%), amount of IRS of DDT and Malathion used (6,444 kg to 43,491 kg) and proportion of malaria cases treated by community health agents (50% to 78%) over five years period (2000-2004) had markedly decreased malaria morbidity and case fatality by 84% and 40% respectively. Yet, the per-

centage of less than five years of age children who slept under bed nets was only 58. 6% in contrast to the proportion of households (81%) who possessed at least one bed net (161). The fact that the proportion of children of less than five years of age and coverage of ITNs at country level implies that ownership does not ensure utilization by target groups. Additionally,, it is difficult to rule out the effectiveness and contribution of ITNs at household level to protect malaria infection. Similarly, a study has also shown that the proportion of under-five years of age children who slept under LLINS in some African countries vary from country to country, ranging from 51.5% to 81.1% (162). The reasons for non-use were households did not have the nets (9.4 to 30.0%), nets were not hanged properly (5.1% to 16.1%) and though nets were hanged but children did not sleep under the net on the night preceding the survey (4.3% to 16.4%).

In areas where unstable transmission of malaria prevails, all age groups are similarly affected. In such situation, giving emphasis to only vulnerable groups is not enough to malaria control (92) as other members of the same household have the probability of being infected and sustain the transmission. A randomized control trial conducted in Ghana on pregnant women did not show difference in reducing malaria risk nor probability of giving low birth weight baby among women who used treated bed nets and the control group (163). Another study conducted in Ghana, showed that the child's family possessing a bed net was not statistically significant for both the group who died of malaria and those who died of other causes in relation to those who survived (164).Moreover, a study done in Tanzania on pregnant women at delivery indicated that regardless of high coverage of ITNs, as 91% reportedly sleeping under bed net on the night preceding the interview, 43% of them reported history of fever and 8% of the placenta had been infected by *Plasmodium* species (165). Thus, regardless of how efficacious an intervention is, if compliance with use is low, the effectiveness will be poor. If ITNs are to be successful against malaria, their effective implementation, promotion and sustainability over time will require appropriate behavioral changes, not just providing bed nets to increase coverage (166).

On the other hand, even if the vulnerable groups properly use ITNs (if at all), there could be possibility of being infected when they were out of beds for various reasons as far as infected mosquitoes are around. Change of mosquitoes' biting behavior is another challenge that makes questionable the protection efficiency of ITNs (167). For instance, study from Bolivia reported that the peak biting time

for A. darlingi was between 19:00 and 21:00, where 40% of the biting took place (168). A recent study conducted in northern part of Ethiopia revealed that the biting of mosquito shifted to early evening (169). According to that study, 70% of biting was between 19:00 to 22:00. Similar study done in central Ethiopian Rift Valley also indicated that the peak biting activities of the vectors occurred before 22:00 (133). During early evening, normally most Ethiopian households, especially in countryside, do not go to bed. Thus, reliance on bed nets in such circumstance needs careful assessment of ITNs possession, proper utilization, and sufficiency for all family members, among other things.

1.4.6. Indoor residual spraying and reduction of malaria

Indoor residual spray (IRS) has been the major protective measures in Africa (158, 170). Studies indicated that IRS reduced 54% to 69% of malaria infection in Africa (171, 172). Proper application of IRS has been known to successfully minimize the impacts of malaria (172-174). Conversely, withdrawal of IRS has resulted in a significant increment of both vectors biting and *Anopheles* mosquito longevity and blood meal index of *Anopheles gambiae s.l.* (175). Thus, recently the proportion of the population protected by IRS substantially increased globally, and in the African Region particularly (176).

Until recently, malaria has been the main health and socioeconomic impediment in Ethiopia (177, 178) accounting for millions of cases and thousands of deaths annually (85, 86). The Government of the Federal Democratic Republic of Ethiopia has been taking major malaria control interventions, including indoor residual spray (IRS) (80). In Ethiopia, IRS was started in the mid 1960s with DDT 75% WP and partly malathion (50% WP) till malaria vector resistance to DDT was detected in 2007 and fully replaced by deltamethrin (pyrethroids) in 2010. Since then, carbamate insecticide has been used for IRS where resistance of malaria vectors to pyrethroids has been detected and malaria outbreaks occur in some areas (87).

In Ethiopia, IRS has been conducted by contract spray-men (not by women) who receive six-days training; and a porter, supervised by a squad leader (179), where district health office plans and implements the IRS with technical and operational inputs from regional, zonal, and central health offic-

es which is considered as ‘district-based model’, as majority of the technical preparation and management takes place at district level; and a team of spray operators (16-20 individuals) moves from district to the community with all the necessary equipment and supplies (180) that makes it less efficient in terms of scarce resources use and coverage of the unit structures.

The Federal Government of Ethiopia has started a health extension program to improve access, equity and utilization of essential health interventions by deploying trained female health extension workers (HEW) who deliver different health packages at a grass root level since 2005 (181, 182) with the assumption that access to and quality of primary health care in rural communities can be improved through transfer of health knowledge and skills to households (183, 184). The participation of these female health extension workers in IRS as squad leaders of the team of spray operators, recruited from the village community with technical support from the district malaria coordinator has been piloted for the first time to shift the ‘district-based model’ to ‘community-based model’ (180).

Generally, malaria is a complex disease and its determinants vary with local conditions. Analysis of malaria relevant data and regular updating of the information is a useful method for prediction of the disease status and preparedness for malaria control (185). It is important to assess and analyze the local contexts that affect the transmission dynamics so that effective control measures can be targeted accordingly. The refined analysis of spatial and temporal distribution of malaria together with socioeconomic and demographic status of the population is thought to improve understanding of the factors that influence the dynamics of malaria in an area (125).

Although factors linked to the dynamics of malaria are complex, the main factors that determine the dynamics of malaria are environmental factors, which limit the survival and longevity of malaria vectors; socioeconomic conditions that affect both exposure level to mosquitoes as well as health-seeking behaviour after infection. The inter-linkages of those driving factors of malaria transmission dynamics are summarized, after reviewing related literatures (60, 89, 109, 110, 133, 134, 141, 186-192), in the following conceptual framework (Figure 1). However, other limiting factors like aspect of health services and mosquito’s intrinsic factors are not included into the framework as those aspects are out of the scope of this study.

1.4.7. Conceptual framework

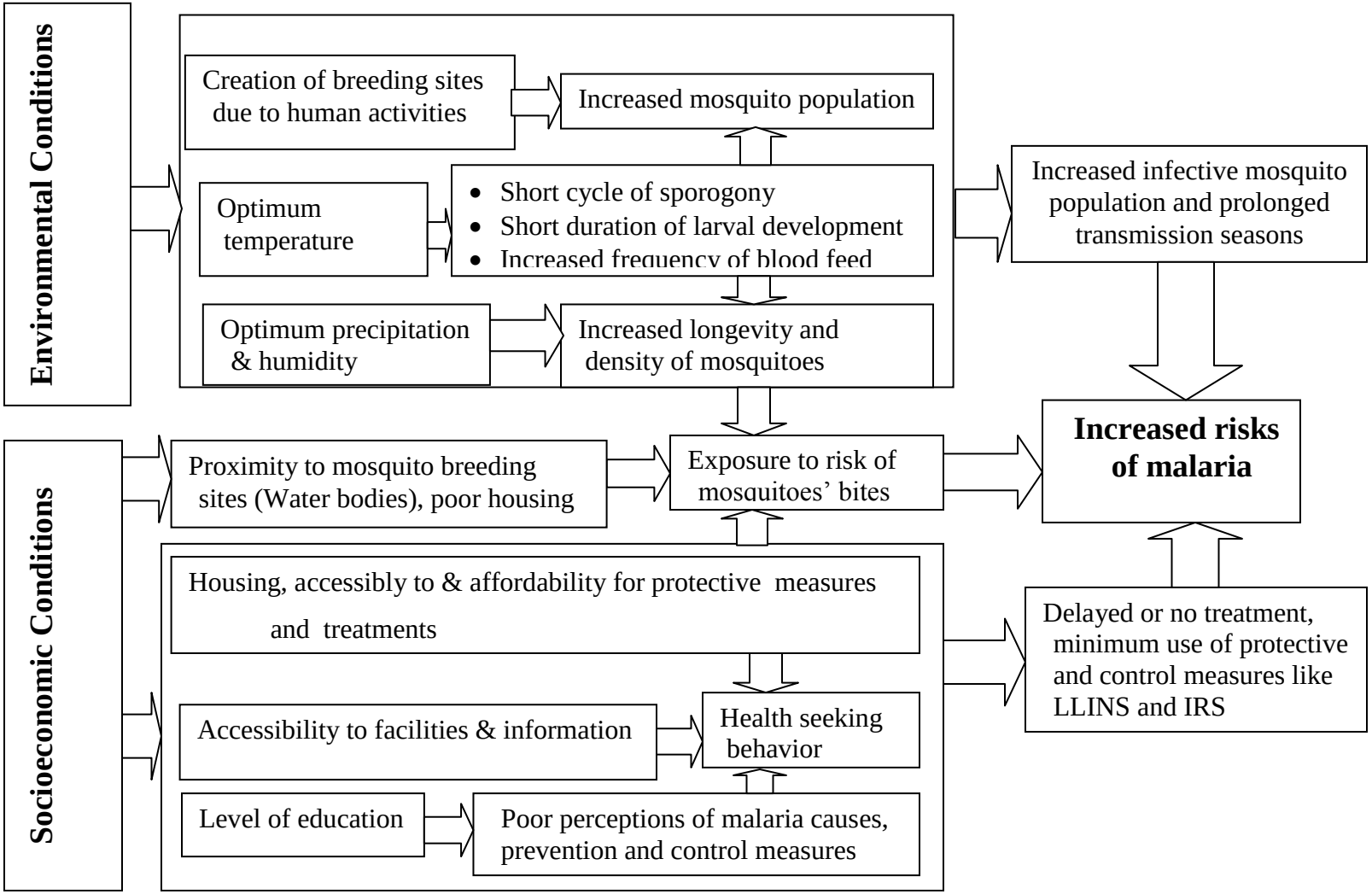

Figure 1 Conceptual framework indicating linkage of factors associated with increased risk of malaria

1.5. Research hypotheses

Different species of mosquitoes prefer different amounts of water, among other things, to perpetuate. As far as other conditions are fulfilled, even temporary and small water bodies can enhance the breeding of mosquitoes; hence can sustain the transmission of malaria. In this case, whether large dams are constructed or not as long as water bodies exist in certain locations and other factors (temperature, humidity, altitude, etc) are conducive for the mosquito breeding, malaria is expected to continue affecting the human population in that area. Yet, it is important to assess whether the presence of relatively large water bodies such as dams (artificial lake), can affect the trends of malaria transmission of a particular area. It is against this background that the following hypotheses are formulated.

1. Trends of malaria prevalence around Gilgel-Gibe Hydroelectric Dam and control sites are similar during the time frame considered;
2. Spatial distribution of malaria around Gilgel-Gibe Hydroelectric Dam was not different for nearby and distant sites during the time frame considered;
3. The possession and utilization of ITN by household members around Gilgel-Gibe Hydroelectric Dam and control sites were not different.
4. Prevalence of malaria, in communities where 'District-based Model' and 'Community-based Model' of indoor residual spray applied, is the same.

2. Objectives

2.1. General objective

The overall objective of this study was to identify malaria Spatiotemporal dynamics and factors affecting malaria risks around Gil-Gel Gibe Hydroelectric Dam and the control area

2.2. Specific objectives

The specific objectives of this study are to:

2.2.1. compare trends of malaria around Gil-Gel Gibe Hydroelectric Dam and control villages over a period of eight years.

2.2.2. analyze spatial distribution of malaria around Gil-Gel Gibe Hydroelectric Dam over a period of eight years.

2.2.3. examine the role of climatic variables on occurrence of malaria both around Gil-Gel Gibe Hydroelectric Dam and control villages.

2.2.4. determine long lasting insecticide treated bed nets possession and utilization among residents of Gil-Gel Gibe Hydroelectric Dam and control villages.

2.2.5. evaluate prevalence of malaria in communities where 'District-based Model' and 'Community-based Model' of indoor residual spraying.

3. Materials and methods

3.1.Study areas

3.1.1. Gilgel-Gibe Hydroelectric Dam area

Gilgel Gibe Hydroelectric Dam (GGHD) is located 260 km south-west of Addis Ababa, capital of Ethiopia. On global positioning, the dam is found at 07.4253^0 to 07.5558^0 N and 037.1153^0 to 037.2033^0 E and started operating in 2004 (193). The area lies within the range of mosquito breeding altitude. Surveys conducted in the area (132, 154, 194) have shown that prevalence of malaria in children was higher by many fold than the national malaria indicator survey report of 2007 (80).

The study villages are located in Omo-Nada, Kersa, Sokoru and Tiro-Afeta Districts and about fifty-five thousand population (11,000 Households) live within 10 km radius of this artificial lake. The main socio-economic activities of the local communities are mixed farming including the cultivation of staple crops, and cattle and small stock raising. All the villages have primary health care facilities.

3.1.2. Control villages

The control villages, which are 15 km far away from the Gil-Gibe Hydroelectric Dam, were identified from Kersa District so that the possible effect of the Dam would not be reflected in the control area. Those villages were selected considering the similarity of geographic features with the Dam area regarding altitude and presence of rivers, but without dam, and equivalent ranges of distance from water bodies as main risk of malaria. Kersa District is located adjacent to the GGHD from the west.

From the District, only two kebeles (smallest administrative units) are found within 10 km radius of the Dam and those villages (Dogoso and Siba) were considered to be influenced by the Dam. Thus, they were included to the study villages of GGHD. Twenty-seven other kebeles (villages) of Kersa District, excluding Dogoso and Siba, are malarious of which 21 are labeled as high risk villages of which eight of them designated as control villages. Like GGHD areas, all those villages have health posts staffed by health extension workers; the residents had similar living patterns and socioeconomic characteristics. Figure 2 below, shows the positions of study sites with respect to map of Oromia regional state within Ethiopia.

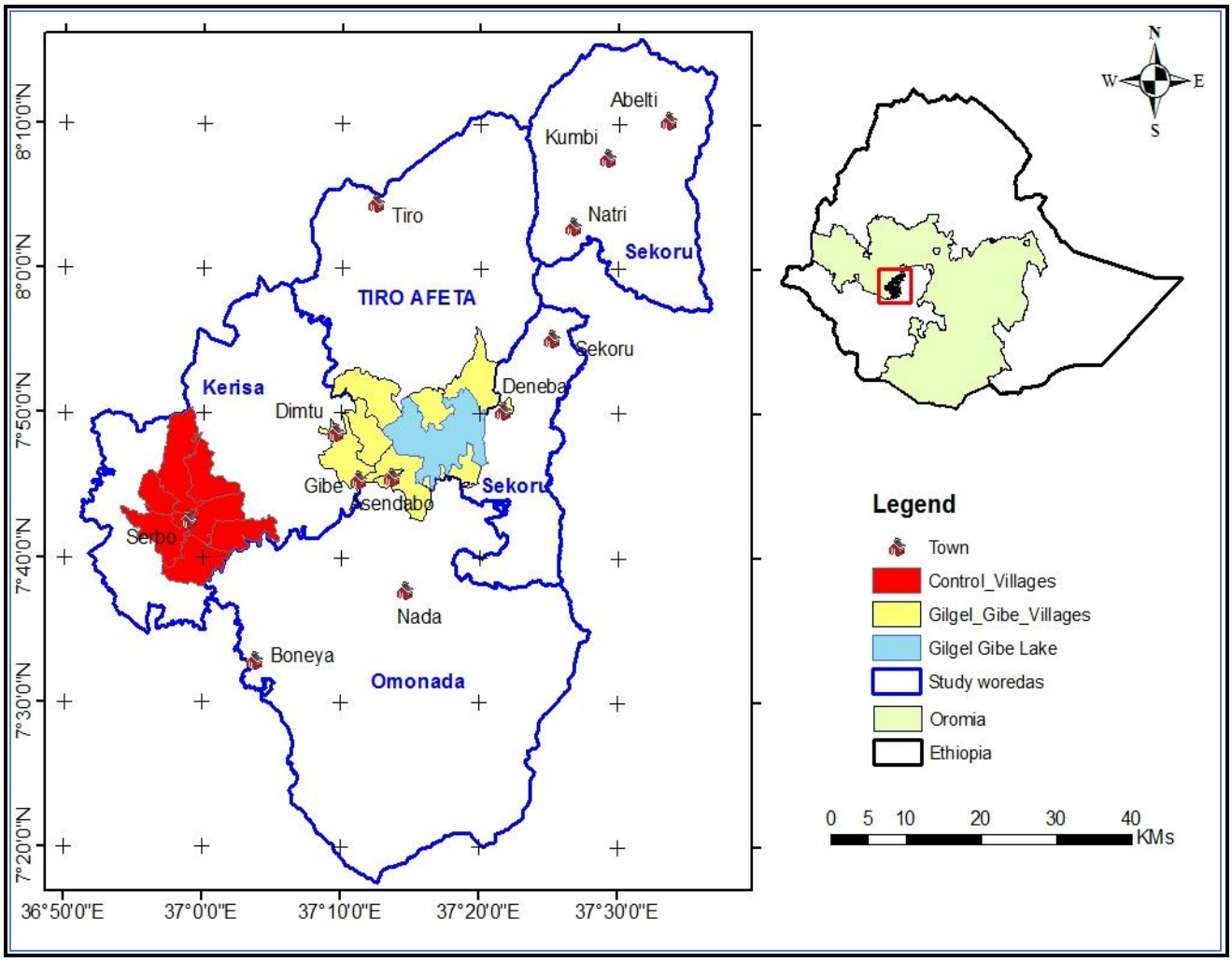

Figure 2 Map of the Study sites within Oromia Regional State of Ethiopia

Raw data source: CSA & JU-IHSR

3.2. Study design

3.2.1. **Trend analysis:** A retrospective comparative study design was employed using data from local health services (health centers and health posts) from both study and control villages. Records of malaria episodes over eight years were retrieved from the local primary health care units (PHCUs) considering selected kebeles of the study areas. Thus, trends of malaria were analyzed by species, affected persons and compared for the two sites retrospectively;

3.2.2. A**nalysis of spatial dynamics:** confirmed malaria case records of eight years were retrieved retrospectively from PHCUs of the GGHD site and traced to their locations. The data were linked to Gilgel Gibe Health and Demographic Surveillance System (GGHD HDSS) data by demographic characteristics and hence linked by location identity of the GGHD HDSS which had been geo-referenced.

3.2.3. **Role of climate variables on malaria transmission pattern:** the correlation of climate variables (rainfall, relative humidity and temperatures) and malaria prevalence was analyzed using spearman's correlation coefficient separately and in common for the study sites. Data were obtained from local health services (health centers and health posts) of both GGHD area and control villages (Kersa District). This was done by reviewing malaria morbidity records of local health facilities pertaining to villages within specified radius of GGHD and control sites since the construction of the Dam.

3.2.4. **Assessment of LLINS possession & utilization:** a cross-sectional comparative survey of households was conducted at both sites using semi-structured questionnaire.

3.2.5. **Comparing malaria prevalence based on blood survey:** this was a community based comparative cross-sectional study where blood samples were collected during peak malaria transmission seasons to evaluate the status of malaria in the study areas with respect to application of indoor residual spraying modalities.

3.3. Source of data/ study population

3.3.1. In Ethiopia, malaria cases are treated both clinically and as confirmed malaria in accordance with the national guideline (86, 87), depending on the degree of diagnostic capabilities at different levels of the healthcare system. Both the presumptive and confirmed cases are registered on preformatted registration books (logbooks) at health facility levels and reported both weekly as well as monthly to next higher level of health management. system. The present study included all malaria records of the local primary healthcare units that were within the environs of GGHD and control villages registered by PHCUs between September 2003 and August 2011 were reviewed.

Additionally, meteorological data (temperature, humidity and precipitation) of the study areas were sought from the National Meteorological Agency South West Ethiopia Regional Branch. Monthly averages of the meteorological variables were computed from daily records and incorporated into malaria trend analysis.

Inclusion and exclusion criteria

Inclusion criteria:

1. All confirmed malaria cases during the period considered and whose names and address were recorded visibly were included into spatial dynamics analysis of the study.
2. All cases, whose date of health service visits and age were recorded, were included in the trend analysis part of the study

Exclusion criteria:

1. Children who were not recorded by proper name and cases whose names invisible on log book were excluded from spatial analysis as tracing was impractical.
2. Cases whose dates of health service visit were not written were excluded from trend analysis.
3. Records of cases that were not linked to the GGHD HDSS data by the location ID were excluded from the spatial analysis.

3.3.2. The source population for household and blood film surveys were residents who lived within 10 kilometres radius of GGHD and those residents in the control villages from Kersa Distract. The respondents of household survey were heads/spouse or any adult person from households which were within the sampled *Gots*. The study population for the blood survey were those residents who were within sampled *Gots* (cluster of about 30 households).

3.4. Sample size determination

3.4.1. Household and blood surveys

An individual was used as a unit of study (sampling unit) for the blood film test and all the members of households, including children, were tested for malaria during the survey. So, taking into account the two study sites (Villages from GGHD and Control villages), two population proportion formulae (195, 196) were used and the sample size was calculated as follows. From a previous study (154), the prevalence of malaria in Gilgel-Gibe was 9.4% and we wanted to detect a difference of 3% (9.4%-6.4%) considering 95% confidence level and power of 80%.

$$n = \frac{\left[\left(Z_{1-\alpha/1}\sqrt{2\pi(1-\pi)}\right)+\left(Z_{1-\beta}\sqrt{\pi_1(1-\pi_1)+\pi_2(1-\pi_2)}\right)\right]^2}{(\pi_1-\pi_2)^2}$$

Where:

$$\pi = \frac{(\pi_1+\pi_2)}{2}$$

n = Desired sample size

π_1 = prevalence of malaria around Gil-gel Gibe Hydroelectric Dam was 9.4% (154).

π_2 = prevalence of malaria in the control area = 9.4%-3% = 6.4%

Z = standard score.

$Z_{1-\alpha}$ = level of confidence at 95%; α = 0. 05

$Z_{1-\beta}$ = 80% power of detecting true difference.

Accordingly, a total of 2269 individuals of all age categories were included in the study, 50.5% from GGHD site and 49.5% from control site where community-based model of IRS was conducted. This means, 8 *Gots* from each site or a total of 16 *Gots* from both sites were included in this study.

Similarly, the number of households included into the household survey of LLIN/ITN was calculated using two population proportion formulae, taking into account the two study sites as follows: from previous study (154), the proportion of households with at least one LLIN/ITN in GGHD villages was 77% and taking 95% confidence level and power of 80% to detect true difference of 4% (77%-

73%). Considering, 10% contingency for non-respondents, number of households included in the survey was estimated. Therefore, the desired sample was calculated to be 1186 households from each site that implies a total of 2,372 households.

3.4.2. Record review

All malaria related cases registered at local primary health care facilities (health centers and health posts) from 10 km radius of GGHD and control villages between September 2003 and August 2011 were reviewed. The time line consideration was based on two grounds: one, on data availability both for GGHD as well as control areas; and the fact that significant change in number of malaria cases, like epidemics occurs in cyclic fashion from 5 to 8 years period in the country (85, 197, 198). So any fluctuation of such cycle could be captured.

3.5. Survey sampling technique/procedure

Initially, both villages (GGHD area and control sites) were arranged into clusters based on their distances they have from GGHD and other water bodies (streams, rivers, ponds, marshy lands, etc) with potential mosquito breeding sites. The total number of clusters was selected based on the assumption that each cluster (*Got*) consists of 25 households (a *Got*, consists of about 30 households according to the current administrative structure).

Then, equivalent number of clusters were categorized as near to and away from the water bodies based on maximum mosquito flight range (117) so that comparison of malaria dynamics between (GGHD area and control villages) as well as within (near and distant clusters) would be possible. The study clusters were identified randomly. Considering probability proportional to sample size, the final sample size was allocated to the selected clusters. Finally, all identified clusters were considered both for the household and blood sample surveys. For the blood survey, considering probability proportional to sample size, the final sample size the desired sample of a total of 2,266 persons were included from the selected clusters (*Gots*).

3.6. Data collection techniques

3.6.1. Health services data

A format (Annex II) was outlined on excel spreadsheet and used to collect the secondary data from local health facilities. Individual level data on malaria morbidity were collected from log books of health facilities (health centers, health posts) and selected villages both from around GGHD and control villages. Variables like: diagnosis results (species of *Plasmodium*, where laboratory facilities were available and clinically treated cases); date of diagnosis, residence, age, sex, etc were collected and registered on computer spread sheet.

Furthermore, confirmed cases of the GGHD villages were traced and linked to location data (altitude, latitude and longitude) to facilitate spatial analysis. Tracing of cases was done by categorizing them according to their residence to small village level and identifying by inspection using demographic variables (name, sex, age). Then, individual cases were related to location and individual identities (ID) which were documented by GGHD HDSS. Finally, using the location ID, the data were linked to GPS readings which were also kept by the GGHD HDSS.

3.6.2. Blood and household surveys

A blood survey was conducted during peak malaria transmission seasons on all segments of population who lived in the sample villages and tests were done using rapid diagnostic test (RDT). Blood film tests were also done on ten percent of the sample for checking quality of the tests. To do so, thick and thin blood films prepared from capillary blood, stained with Giemsa and 100 oil immersion fields were examined following WHO standard procedures (199). Results of blood samples and demographics of the study populations were recorded on a prearranged format (Annex III).

Semi-structured questionnaire was considered best for determining the frequency of beliefs, opinions, views, perceptions and reported practices pertaining to malaria prevention and control, upon which more valid generalizations could be based (43, 105, 122, 200). So, using semi-structured questionnaire, data on demographic characteristics, socio-economic information, LLIN possession and utilization of the households' members were collected. For this purpose tools (Annex II) have been developed by reviewing relevant literatures (201-204).

3.6.3. Meteorological data

Daily records of meteorological data such as precipitation, relative humidity and temperature for the study period of the study areas were sought from the National Meteorological Agency, South-West Regional Branch. Monthly averages of the meteorological variables were computed both for maximum and minimum of the variables and incorporated to malaria trend analysis.

3.7. Data processing and management

3.7.1. Health service data

The current study included all the presumptive and confirmed malaria records of the local PHCUs that were registered by the PHCUs of the two study sites between September 2003 and August 2011. The timeline consideration was based on data availability and the fact that significant change in the number of malaria cases, such as epidemics, occurs in cyclic fashion from five to eight-year periods in the country (85, 197, 198), in order that any fluctuation of such cycle could be captured. A format was prepared on a computer spreadsheet (Excel) to capture the secondary data from log books of local PHCUs of the area. Individual level data on malaria morbidity; such as, diagnosis results; dates of diagnoses; available demographic data (residence, age, sex) were registered on computer spreadsheet.

Data on malaria episodes records of the PHCUs of the study sites were transferred to Excel spreadsheet, checked for completeness, coded; then, prepared data of malaria were exported to STATA statistical software version 12. Data were then aggregated by sex, age and village to describe the distribution of malaria prevalence among the study subjects and among the villages. To derive denominator of the trend analysis, mid-year population of the villages was calculated for each time period and for different age categories accordingly. For the GGHD site, the denominator derived from the GG HDSS data, whereas that of the control site was obtained from the census information and Kersa district population data records. The district information was also cross-checked and it was found to be with the data of household survey results.

To facilitate spatial analysis, location records of GGHD HDSS (GPS data) were exported to ArcGIS version 9.3 and shape file was prepared in degree decimals. The study setting was categorized in to five buffer zones considering distance interval of one kilometer. The altitude of the area was also

categorized into six levels as up to 1700, 1701 to 1800, 1801 to 1900, 1901 to 2000, 2001 to 2100, and above 2100 meter above sea level taking into account the narrow range of this micro-epidemiological setting. Then, the shape file data were exported to STATA statistical software. Individual level data were cross-linked to location references by unique identification codes for the spatial analysis. Incidence rate ratio (IRR) was used to estimate the level of malaria episode count ratios among the buffer zones of the GGHD as well as among the altitudinal levels.

The number of base population in the buffer zones and in the ranges of altitude were incorporated as an offset variable to adjust for the underlying population density while computing the IRRs among both the buffer zones and ranges of the altitude. The temporal variation in malaria distribution was noted by parasite species and month, quarters and years. Furthermore, the inter-annual trend of the malaria episodes was analyzed both for all positive cases and for *P. vivax* malaria relative to *P. falciparum* using the IRR to detect change in magnitude of the malaria episodes by years relative to the initial year.

3.7.2. Household and blood surveys data

Dependent variables, perceptions and practices regarding existing malaria prevention and control tools, including LLIN possession and utilization, were analyzed using multinomial regression models (205). Data were entered into EpiData entry 2 software and exported to Statistical Package for Social Sciences (SPSS) version 20 for Windows, edited, cleaned, and analyzed. Durable household assets, sanitation facilities, farm animals, grain produced in the preceding year of the survey and housing conditions were considered in the construction of household relative wealth index (RWI) using principal component analysis. Socioeconomic and demographic characteristics of the study subjects were summarized in a table. Furthermore, the study subjects were compared based on means of continuous variables such as age, family size and income using t-test for differences of means. Similarly, data on blood samples and demographics were recorded in a prearranged format. Data were then entered into EpiData version 3.1 and exported to SPSS version 20 for Windows, aggregated by sex, age, village and household RWI to describe the distribution of malaria prevalence among study subjects and among the villages with respect to these variables

3.8. Data quality assurance

3.8.1.Health service data: To ensure quality, data collection tools (annex IV) were used. Data were entered into computer software, checked, edited, cleaned and analyzed. The usual weakness of secondary data (like diagnosis quality in this case) was similar for both GGHD and control areas so that comparability of the two sites would not be affected.

3.8.2. **Household survey:** To ensure quality, data collection questionnaire (Annex II) was pre-tested, check lists and field guides were used. Adequate training was given to data collectors. Daily on job supervision was done by field level supervisors. Furthermore, each questionnaire and format were checked for completeness and proper fill.

3.8.3.Blood film tests: To maintain the validity of the blood examinations for *Plasmodium* species, trained and experienced health extension workers, who were supervised by laboratory technicians/technologists, conducted the collection and examination of blood tests. Blood films were taken from ten percent of the participants and analysed by experienced laboratory technologists by microscopy as quality check of the RDT tests.

Additionally, the household and blood surveys, EpiData software version 3.1 was used for data entry so that error entries were control based on defined rules while designing data entry template.

3.9. Ethical considerations

Ethical clearances were obtained from the Addis Ababa University College of Health Sciences Ethical Review Board; Oromia Regional Health Bureau Ethical Review Committee. Furthermore, Jimma Zonal and District Health offices as well as local administrators were communicated by formal letters for their cooperation and community consents; consent was obtained from study subjects and for children parents or caretakers were communicated for consent. Individuals who were positive for malaria were treated with proper anti-malarial drugs by collaborating with Oromia Regional Health Bureau, Jimma Zone Health Department and the respective districts health offices based on the Ethiopian Malaria Diagnosis and Treatment Guideline (86).

Individual information was kept confidential and the names of individuals were removed both from filled questionnaires as well as secondary data of health services and identified only by identification numbers. Hard copies of the information were kept in a locked cupboard and the results were communicated in an aggregated manner. The study subjects were left free when they refused to give blood sample and/or responses to questions and such refusal did not have any impact on them to get health services they may need at any time. Furthermore, "got" (aggregates of households) where ongoing studies regarding malaria, were being conducted were not included into the household and blood surveys of this study.

Blood samples were collected by trained health workers/laboratory technicians who have experience in blood sample collection. Sterilized blood lancets were used to avoid infection. There might be slight discomfort, pain and bleeding during the procedure. However, we did not wish this to happen; yet, this doesn't cause lasting pain and it is negligible compared to the benefit of identification of malaria parasites when present which cause disease, disability and even death if left untreated properly. Those individuals who became positive for malaria were treated with proper anti-malarial drugs based on the Ethiopian Malaria Diagnosis and Treatment Guideline (86).

3.10. Brief Summary of methods

Table 1 Summary of methodology

S. No	Specific objectives	Study designs	Sample size	Data sources (Study population)	Data collection techniques	Analytical models used
1	To analyze trends of malaria	Comparative retrospective	163,918 malaria episodes registered between September 2003 and August 2011 in the study areas.	Malaria records of local health facilities	Record review and use of computer spreadsheet	Descriptive, Multinomial logistic regression
2	To assess spatial distribution of malaria around GGHD	Comparative retrospective	Positive malaria episode records between September 2003 and August 2011 & linked to GGHD HDSS site (# 10,443)	Malaria episode records of PHCUs & GPS data from GGHD HDSS	Record review GPS data	Poisson model for risk ratios among buffer zones and altitudinal levels
3	To analyze role of climatic variables on malaria	Comparative retrospective	163,918 malaria episodes registered between September 2003 and August 2011	Malaria episode records of PHCUs and weather data records	Record review and use of computer spreadsheet	Spearman's correlation coefficient
4	To determine the possession and utilization LLINS	Comparative cross-sectional	2,372 respondents	Respondents of house household survey	Questionnaire based household survey	Multiple logistic regression and F tests for proportions
5	To compare malaria prevalence with respect to application models of IRS	Comparative cross-sectional	2,269 sample individuals	Community based blood survey	blood survey of household members	Descriptive

4. Results

The main findings of the study are summarized under five sub-headings. Namely: Analysis of Trend of Malaria Prevalence, Dynamics of *P. falciparum* and *P. vivax* in a Micro-ecological Setting, Southwest Ethiopia: Effects of Altitude and Proximity to a Dam, Correlation of Climate Variability and Malaria: A Retrospective Comparative study, Predictors of Long Lasting Insecticide treated bed nets Possession and Utilization and Potential Shift of Indoor Residual Spray from District-based Model to Community-based Model.

4.1. Analysis of Trend of Malaria Prevalence in Southwest Ethiopia: A Retrospective Comparative Study

This retrospective study assessed records of 163,918 malaria episodes registered over eight years (between September 2003 and August 2011) period. Overall, the male to female population ratio was 1.08: 1 and slightly higher for Gilgel Gibe Hydroelectric Dam (GGHD) site (1.12:1 vs 1.06: 1) than the control site. Close to a third (32.7%) of cases were from GGHD site and two-third (67.3%) of them were from the control site. As depicted in table 2, the under-five age group has constituted 12.0% of all cases, which was higher in the control site (12.7% vs 10.5%) than GGHD site. The proportion of children aged from 5 to 14 years was 28.0% (28.3% in the control vs 27.6% in GGHD); also the proportion in the age group 10 to 14 years was higher among the control (16.3% vs 14.4%) than the GGHD site. On the other hand, the composition of adult cases aged fifteen years and above was higher in the GGHD site (62.3% vs 59.0%) than the control site (Table 1 of paper one).

As indicated in table 2 below, close to two-third (60.5%) of the 163,918 cases were confirmed malaria cases, whereas more than one-third (39.5%) of them were clinical malaria cases, including probable malaria cases. Overall, *P. falciparum and P. vivax* malaria accounted for one-third and a quarter of all the cases respectively across all age groups. Pertaining to the species composition, among the confirmed cases, P. falciparum constituted

54.6% (60.4% in GGHD and 52.3% in the control), *P. vivax* accounted for 41.6% (33.6% in GGHD and 44.7% in control) and mixed species was 3.8% (6.0% in GGHD and 3.0% in control) of the confirmed cases.

There have been differences in the composition of Plasmodium species between the study sites. In the under five years of age group, all the *Plasmodium species* were significantly higher in the control site than the GGHD site There have been higher proportion of infections in control site by both *P. falciparum and P. vivax* species in all age categories. Infection by *P. falciparum* and *P. vivax* malaria was 1.5 and 2.2 times more likely to occur in the control site compared to GGHD site among the under five years of age group. The prevalence of *P. falciparum* and *P. vivax* was respectively more than two and three times likely to occur among children five to fourteen years age group in the control sites compared to the GGHD site. Among the adults fifteen years and above years of age, the prevalence of *P. falciparum* and *P. vivax* were 1.7 and 2.7 respectively more likely to happen in the control sites compared to the GGHD site (Table 2).

Table 2 Distribution of malaria cases by age group, diagnosis and study sites, Jimma zone, southwest Ethiopia, September 2003-August 2011

Age group (year)	Diagnosis	GGHD N (%)	Control N (%)	Odds Ratio (C.I.)
<5	*P. falciparum*	1437 (23.8)	4606 (76.2)	0.65 (0.53,0.80)*
	P. vivax	901 (18.2)	4056 (81.8)	0.46 (0.38,0.57)*
	P. mixed	145 (32.4)	302 (67.6)	1
	Sub total	**2483 (21.7)**	**8964 (78.3)**	
5-9	*P. falciparum*	2293 (33.6)	4530 (66.4)	0.47 (0.39,0.56)*
	P. vivax	1239 (23.9)	3954(76.1)	0.29 (0.24,0.35)*
	P. mixed	261 (52.1)	240(47.9)	1
	sub total	**3793(30.3)**	**8724 (69.7)**	
10-14	*P. falciparum*	2260 (27.2)	6053 (72.8)	0.45 (0.38,0.54)*
	P. vivax	1323 (20.5)	5143 (79.5)	0.31 (0.26,37)*
	P. mixed	263 (45.1)	320 (54.9)	1
	sub total	**3846 (25.0)**	**11516 (75.0)**	
15+	*P. falciparum*	10939 (33.2)	22045 (66.8)	0.61 (0.57,0.67)*
	P. vivax	5947 (24.2)	18676 (75.8)	0.40 (0.36, 0.43)*
	P. mixed	1011 (44.5)	1262 (55.5)	1
	sub total	**17897 (29.9)**	**41983 (70.1)**	
Total	*P. falciparum*	16929 (31.3)	37234 (68.7)	0.58 (0.54,0.61)*
	P. vivax	9410 (22.8)	31829 (77.2)	0.37(035,0.40)*
	P. mixed	1680 (44.2)	2124 (55.8)	1
	Total	**28019 (28.2)**	**71187 (71.8)**	

As shown in table 3 below, the proportion of *P. falciparum* among under five children was 52.0%. Conversely, the overall proportion of the *P. vivax* among this age group was 43.3%. The proportion of *SM* was 3.9% in the under children. The overall compositions of *Plasmodium species* was similar for the children age group from five to nine years and those in the age range of ten to fourteen years with only 0.4% more *P. falciparum* in the ten to fourteen years and 0.6% more *P. vivax* in the other age group.

A larger proportion of the *P. falciparum* was observed in the years 2003/4 (59.2%) and 2006/7 (58.8%), whereas a lower proportion of the *P. falciparum* was noticed in 2007/8 (48.0%) and in 2010/11 (37.7%). Higher proportion of *P. vivax* was registered in 2007/8 (49.1%) and in 2010/11 (47.2), whereas lower proportion was seen in 2003/4 (27.8%). On the other hand, higher proportion of the *SM* was recorded in 2003/4 (13.0%) and in 2010/11 (15.1%) and lower proportion was seen in 2006/7 (0.5%) and in 2008/9 (1.9%).

There were small variations among the individual years regarding to proportion of *P. falciparum* in the under five years of age children. Except inter annual variations, there was no much difference in the composition of *Plasmodium species* between children in the age group from ten to fourteen years and adults fifteen years and above. There was only a 1.0% more *P. falciparum* in the adult group and conversely 1.0% more *P. vivax* in the children group. The *SM* was the same (3.8%) in both groups (Table 3).

Table 3 Distribution of confirmed malaria cases by age group, *Plasmodium* species and years of health service visits, Jimma zone, Southwest Ethiopia, September 2003-August 2011

Age (years)	Species Types	Years of health facility visits								Total # (%)
		2003/4 # (%)	2004/5 # (%)	2005/6 # (%)	2006/7 # (%)	2007/8 # (%)	2008/9 # (%)	2009/10 # (%)	2010/11 # (%)	
<5	P. f	313 (59.2)	1189 (55.4)	331 (54.0)	459 (58.8)	1254 (48.0)	812 (57.0)	1590 (51.5)	95 (37.7)	6043 (52.8)
	P. V	147 (27.8)	914 (42.6)	262 (42.7)	317 (40.6)	1284 (49.1)	586 (41.1)	1328 (43.0)	119 (47.2)	4957 (43.3)
	SM	69 (13.0)	43 (2.0)	20 (3.3)	4 (0.5)	77 (2.9)	27 (1.9)	169 (5.5)	38 (15.1)	447 (3.9)
	Subtotal	**529**	**2146**	**613**	**780**	**2615**	**1425**	**3087**	**252**	**11447**
5-9	P. f	467 (62.9)	1099 (54.8)	349 (56.6)	565 (55.8)	1275 (48.7)	985 (61.3)	1865 (54.5)	218 (43.8)	6823 (54.5)
	P. v	169 (22.8)	846 (42.2)	248 (40.2)	432 (42.7)	1299 (49.6)	608 (37.8)	1395 (40.8)	196 (39.4)	5193 (41.5)
	SM	106 (14.3)	59 (2.9)	20 (3.2)	15 (1.5)	43 (1.6)	14 (0.9)	160 (4.7)	84 (16.9)	501 (4.0)
	Subtotal	**742**	**2004**	**617**	**1012**	**2617**	**1607**	**3420**	**498**	**12517**
10-14	P. f	598 (60.5)	1479 (55.2)	471 (58.7)	721 (60.5)	1514 (45.9)	1167 (60.2)	2200 (53.9)	163 (42.0)	8313 (54.1)
	P. v	245 (24.8)	1150 (42.9)	302 (37.7)	450 (37.8)	1717 (52.1)	754 (38.9)	1674 (41.0)	174 (44.8)	6466 (42.1)
	SM	145 (14.7)	49 (1.8)	29 (3.6)	20 (1.7)	67 (2.0)	16 (0.8)	206 (5.0)	51 (13.1)	583 (3.8)
	Subtotal	**988**	**2678**	**802**	**1191**	**3298**	**1937**	**4080**	**388**	**15362**
≥ 15	P. f	1818 (61.1)	5359 (56.5)	1670 (55.5)	2776 (56.6)	6231 (48.9)	5017 (62.3)	9187 (55.2)	926 (44.2)	32984 (55.1)
	P. v	754 (25.3)	3896 (41.1)	1243 (41.3)	2066 (42.1)	6226 (48.9)	2982 (37.0)	6625 (39.8)	831 (39.7)	24623 (41.1)
	SM	404 (13.6)	225 (2.4)	97 (3.2)	61 (1.2)	273 (2.1)	57 (0.7)	820 (4.9)	336 (16.1)	2273 (3.8)
	Subtotal	**2976**	**9480**	**3010**	**4903**	**12730**	**8056**	**16632**	**2093**	**59880**
Total	P. f	3196 (61.1)	9126 (56.0)	2821 (56.0)	4521 (57.3)	10274 (48.3)	7981 (61.3)	14842 (54.5)	1402 (43.4)	54163 (54.6)
	P. v	1315 (25.1)	6806 (41.7)	2055 (40.8)	3265 (41.4)	10526 (49.5)	4930 (37.9)	11022 (40.5)	1320 (40.9)	41239 (41.6)
	SM	724 (13.8)	376 (2.3)	166 (3.3)	100 (1.3)	460 (2.2)	114 (0.9)	1355 (5.0)	509 (15.8)	3804 (3.8)
	Total	**5235**	**16308**	**5042**	**7886**	**21260**	**13025**	**27219**	**3231**	**99206**

** **P. f**: Plasmodium falciparum; **P. v**: Plasmodium vivax; **SM**: Plasmodium mixed.*

With regard to the composition of the *Plasmodium species* with respect to the monthly average of number of cases, different patterns in years round were noticed. As illustrated in figure 2 below, in the GGHD site the *P. falciparum* (brown line) exhibited one minor and another major peak transmission. Starting from February, episodes of *P. falciparum* showed gradual increase and reached the minor peak in May. The major peak transmission period was from September through November when 44.5% of the annual infection of *P. falciparum* was registered.

The monthly distribution of *P. vivax* (black line) in the GGHD site was almost similar. The *P. vivax* occurrence in the GGHD site was mostly below two percent, except during the months September to October when it reached about two and half percent of the annual transmission. The mixed species (*SM*) infection (green line) was generally far below one percent, except during the month of October.

In the control site, staring from May there was gradual but steady increment of *P. falciparum (red line)* through September, then transmission accelerated and reached its main peak (9.6%) in November. In the control site, close to a third of the annual transmission of *P. falciparum* took place from October to December. From December to February, there was steady decline. Then, it showed a minor peak (7.1%) in March and exhibited again decrement where it reached the lowest level (4.6%) in April.

Regarding *P. vivax* monthly distribution (blue dashed line) in the site, like *P. falciparum* its two moderate transmission peaks were in March and November. Its transmission pattern from February to April was similar with that of *P. falciparum*, which was minor peak. After the month of April, P. vivax transmission showed very slow decline and reached its lowest level (3.5%) in September. Then, it rose gradually and reached its second peak in November. The *SM* (aqua line) monthly average distribution was almost the same and it was below five infections among a thousand population throughout the year in the control site (Fig 3).

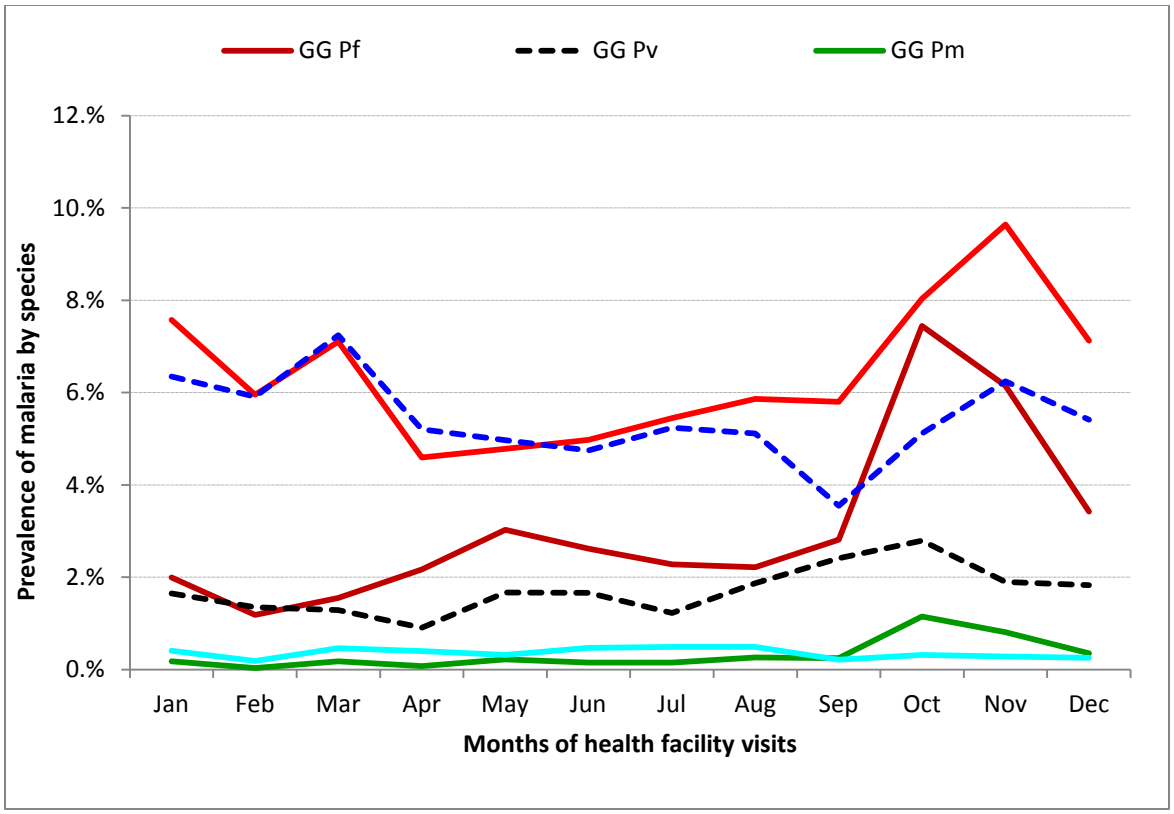

Figure 3 Monthly average trends of confirmed malaria prevalence by *Plasmodium* species and sites, Jimma zone, Southwest Ethiopia, September 2003-August 2011

The proportion of species composition in the two study sites showed different patterns over the eight years period. As depicted in figure 4 below, the proportion of *P. falciparum* (aqua line) was generally higher in the GGHD site relative to *P. vivax*. During the 2003 and 2004, it was slightly less than 50%. However, it reached 60% in 2005 though it showed some declining the following year. Starting from 2006, it steadily rose and reached above 70% in 2009. In 2010, the proportion of *P. falciparum* declined once again to about 50% of the malaria infections.

On the other hand, the proportion of *P. vivax* (brown dotted line) in the GGHD site was below 20% in 2003. However, it escalated to more than 40% in the following year. It declined again in 2005 to about 32% and gradually increased for the next subsequent two years. From 2007 to 2009, there was another gradual decline to about 25%. It increased to nearly 40% in 2010 though it showed another decline in 2011. Regarding *SM* (purple

dashed line), it was about 30% in 2003, but sharply dropped to less than 10% in 2004, then steadily decreased further for the subsequent three years. It was below one percent in the years from 2007 to 2009; however, there was gradual increase of the *SM* proportion in the following two years.

In the control site, the proportion of *P. falciparum* (blue line) initially was higher than that of *P vivax*. However, gradual and steady decline of the ***P. falciparum*** proportion was evident over the eight years. Conversely, the proportion of *P. vivax* (red dotted line) increased from below 20 % in 2003 to over 70% in 2011. The proportion of *SM* (green dashed line) was generally similar and at lower level in the control site, except in 2011 when it exhibited a small augment (Fig 4).

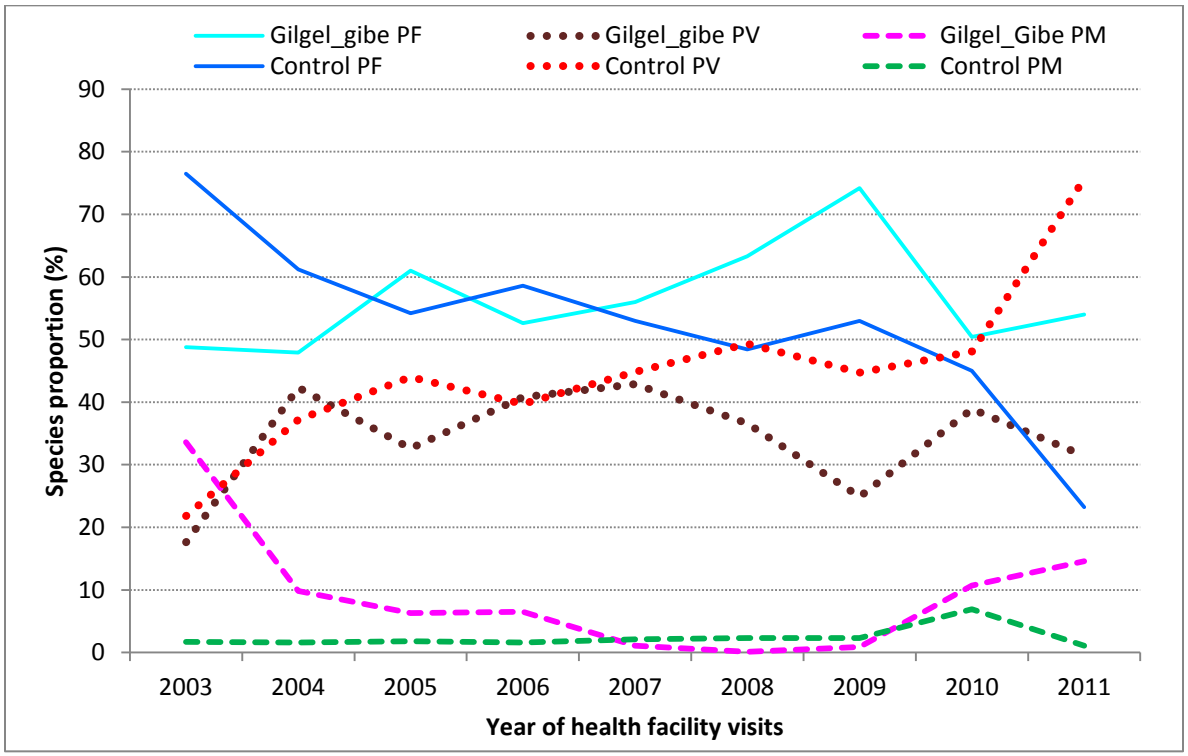

Figure 4 *Plasmodium species* proportions of confirmed malaria by sites and year, Jimma zone, Southwest Ethiopia, September 2003 to August 2011

Comparison of all confirmed malaria yearly prevalence over the study period in the two study sites was also carried out. During 2003, the prevalence of malaria was at similar levels in both sites and decreased in similar fashion in the first year. However, as depicted in figure 5, after 2004, the prevalence of malaria in the control site (green line) was higher than that of the GGHD site. In the control site, there were several peaks of malaria. Especially, the periods from 2004 to 2005, 2006, 2007, and 2009 to 2010 characterized by major peaks of malaria.

However, after 2010, there was a drastic drop of the prevalence of malaria in the control site. In contrast to the control site, the prevalence of malaria in the GGHD site (red line) was lower. During the first two years malaria prevalence declined in the GGHD site though slight peak was observed in 2004. Since 2005 persistent rise in malaria prevalence, had been observed in general. Particularly, there was at least a peak of malaria prevalence yearly from 2007 through 2009. The peak of the prevalence that observed in 2009 was the highest of the other years in the GGHD site. After 2009, malaria prevalence declined in the GGHD site as well (Fig 5).

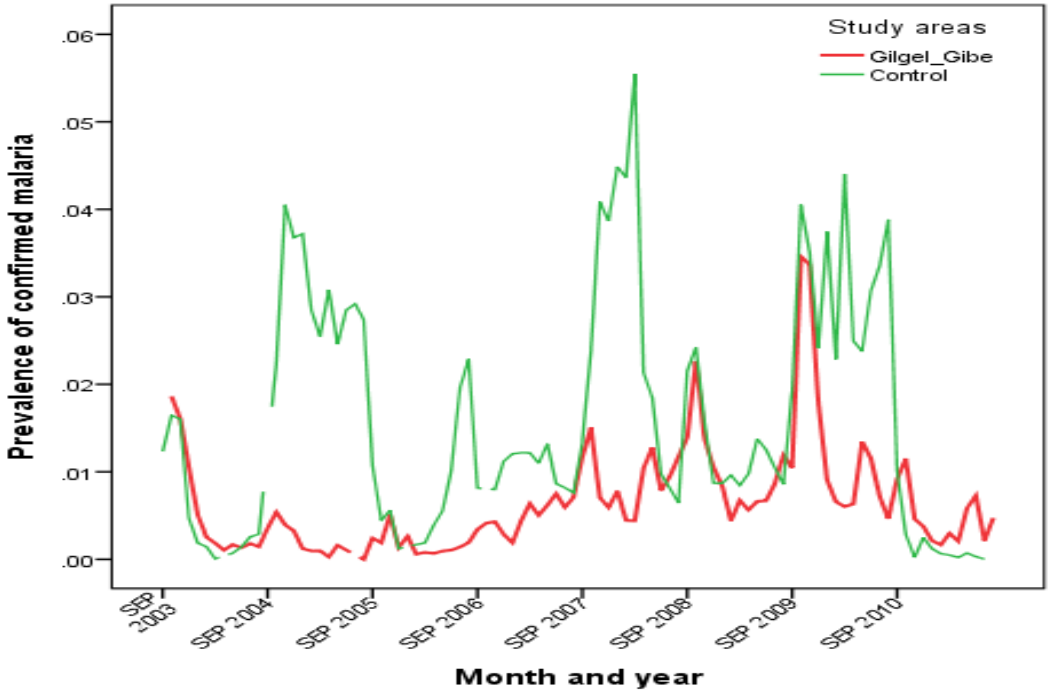

Figure 5 Trend of all confirmed malaria prevalence by study site and year, Jimma zone, southwest Ethiopia, September 2003-August 2011

Malaria prevalence decreased both in GGHD and control sites from September 2003 to August 2004. Then, the patterns of malaria prevalence in the sites gradually followed different patterns. In the GGHD area, malaria prevalence (red line) was low, starting from December 2003 to September 2006 with two small rises between September and November 2004 and 2005. However, there was persistent and gradual increment of malaria prevalence during subsequent four years with peak transmission of different magnitude in September 2007, 2008 and 2009. The peak in 2008 coincided with that of the control area peak. The rise of prevalence in September 2009 was the highest one in the GGHD area. Since March 2010, malaria prevalence decreased steadily in the GGHD area.

In the control site (green line), the prevalence of malaria had been excessively higher since September 2004. From September 2004 onwards, the malaria prevalence remained at higher levels throughout the year, and dropped sharply in September 2005 and further reduced in December 2005. From March to September 2006, there was a peak during the six months. From September 2007 to July 2008, the highest rise of malaria prevalence was noticed in the control site. There were still peaking of malaria prevalence in the area during September to December 2008 and September 2009 to September 2010 for about two subsequent years until it dropped drastically almost to zero level in September 2011 (Fig 5).

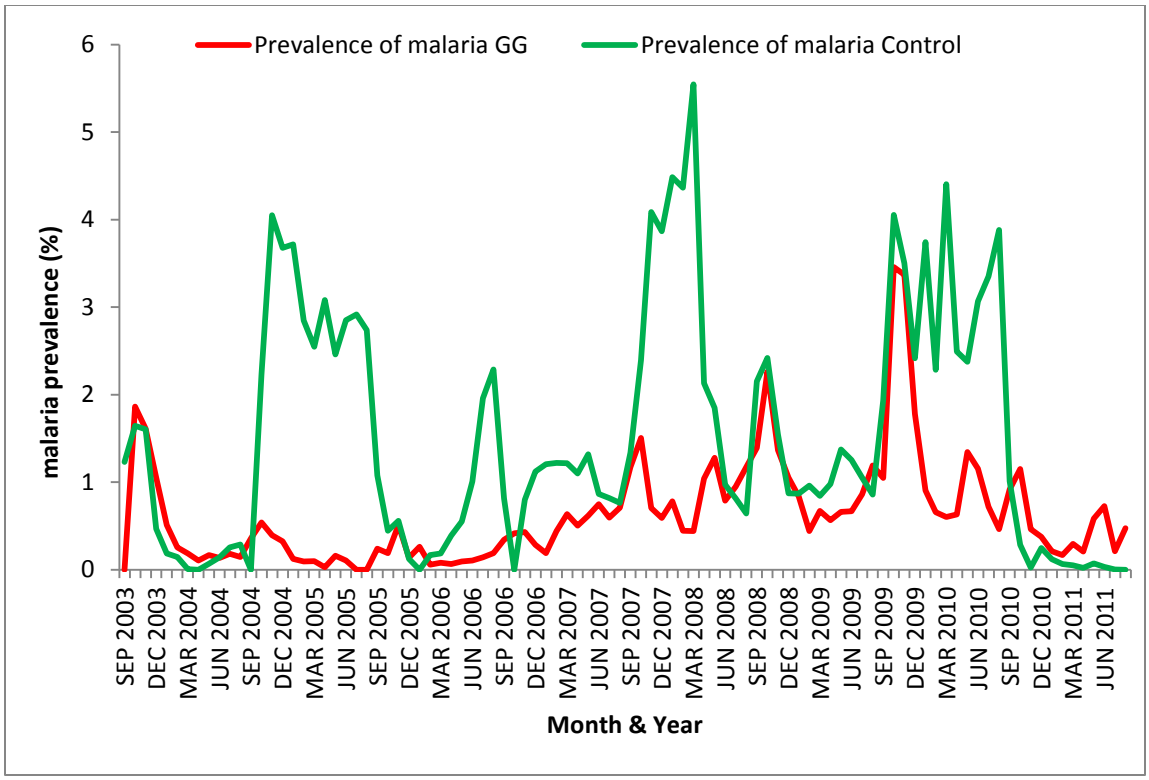

Figure 6 Trend of average confirmed malaria prevalence by quarter, year and study sites, Jimma zone, Southwest Ethiopia, September 2003-August 2011

The patterns of Plasmodium species composition over the study period were also assessed by study sites. As indicated in figure 7 below *P. falciparum* infection showed different patterns in the two study sites. In the GGHD site, *P. falciparum* (black dashed line) infection was lower in 2003 and further declined in the following two years. Since 2006, *P. falciparum* steadily escalated and reached highest level of above eleven percent in 2009 forming only one major peak of transmission. Then, the prevalence of *P. falciparum* sharply decreased over the following two years and reduced to below two percent in 2011.

On the other hand, *P. vivax* malaria prevalence (purple dashed line), gradually increased since 2006 in the GGHD site over the following two years and leveled about to be plateau in the subsequent two years after 2008, then regressed to less than one percent in 2011. The mixed species (*SM)*, denoted by green dashed line, was found to be lower in the GGHD site throughout the eight years of this study.

In the control site, both *P. falciparum* (red line) and *P. vivax* (blue line) showed three main peaks of transmission in the eight years period. In the first two years, there was a persistent increase of cases and reached the first peak in 2005, then reduced in 2006. Again, it gradually rose and reached another peak in 2008. In 2009, there was a slight decline of *P. falciparum* cases, although the number of cases rose once again in 2010 when it reached its third peak. Before 2008, *P. falciparum* was higher than *P. vivax;* however, in 2008 and 2010 the prevalence of *P. vivax* took a lead. Starting from 2010, both *P. falciparum* and *P. vivax* reduced drastically and reduced almost to zero level in 2011. The prevalence of *SM* malaria (aqua line) was low and below one percent in most cases except in 2011 (1.8%) in the control site (Fig 7).

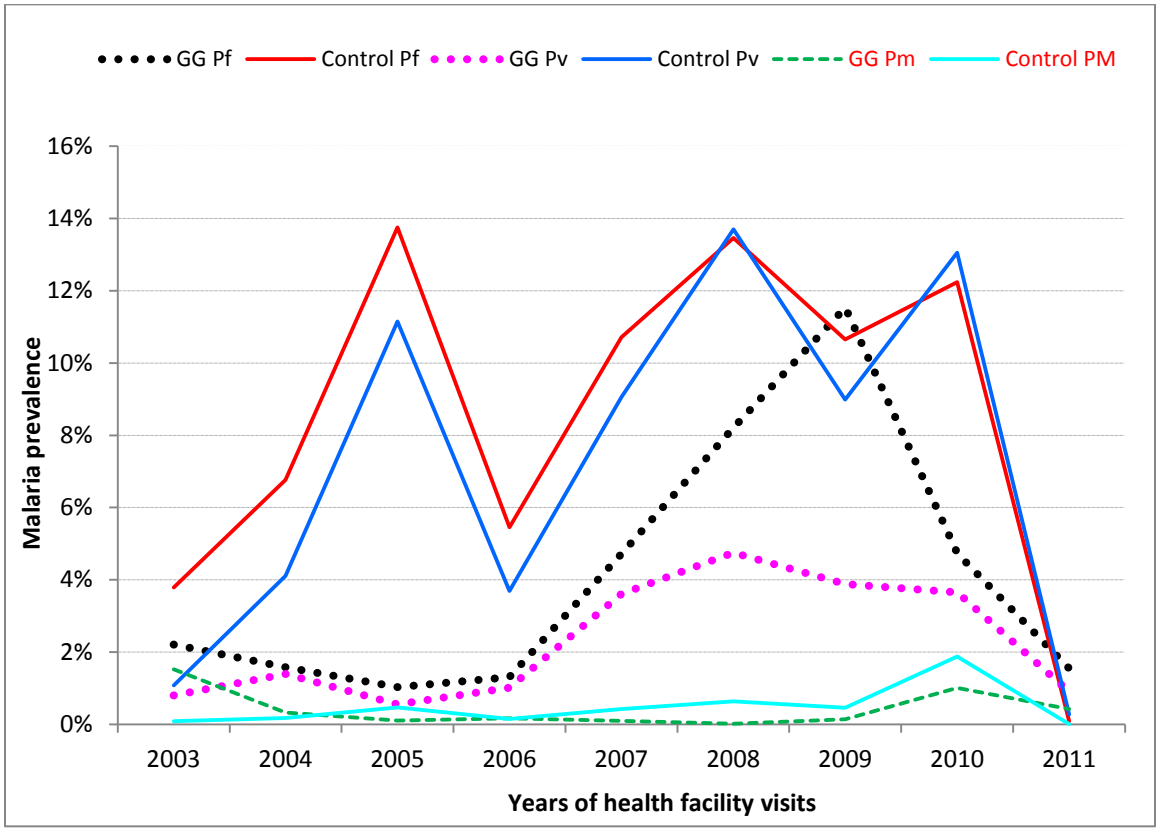

Figure 7 Prevalence of confirmed malaria by species, sites and year, Jimma zone Southwest Ethiopia September 2003-August 2011

There was variation of trend of confirmed malaria among different age groups as well as year-to-year trends. In the control site, children in the age group 10 to 14 years were the most affected ones throughout the study period (red line). Especially, in 2005 (89.5%), 2008 (99.0%) and 2010 (82.6%), when major peak transmissions of malaria noticed, the prevalence of the disease in this age group was higher by many fold than adults. The peak transmissions appeared to be more pronounced among the children below fifteen years, particularly those in the age group 10 to 14 years.

In the GGHD site, children 10 to 14 years were the most affected too (blue line). The under five and five to nine years age groups were the second most affected one in both sites. There was not much pronounced risk difference between these age categories (black dotted and yellow line for the control site and brown and aqua dotted lines for the GGHD site), both were at similar risk level. The prevalence of the diseased was higher in the control site among all age groups, in spite of the fact that prevalence of the disease was lower in adults age group in general (Fig 9).

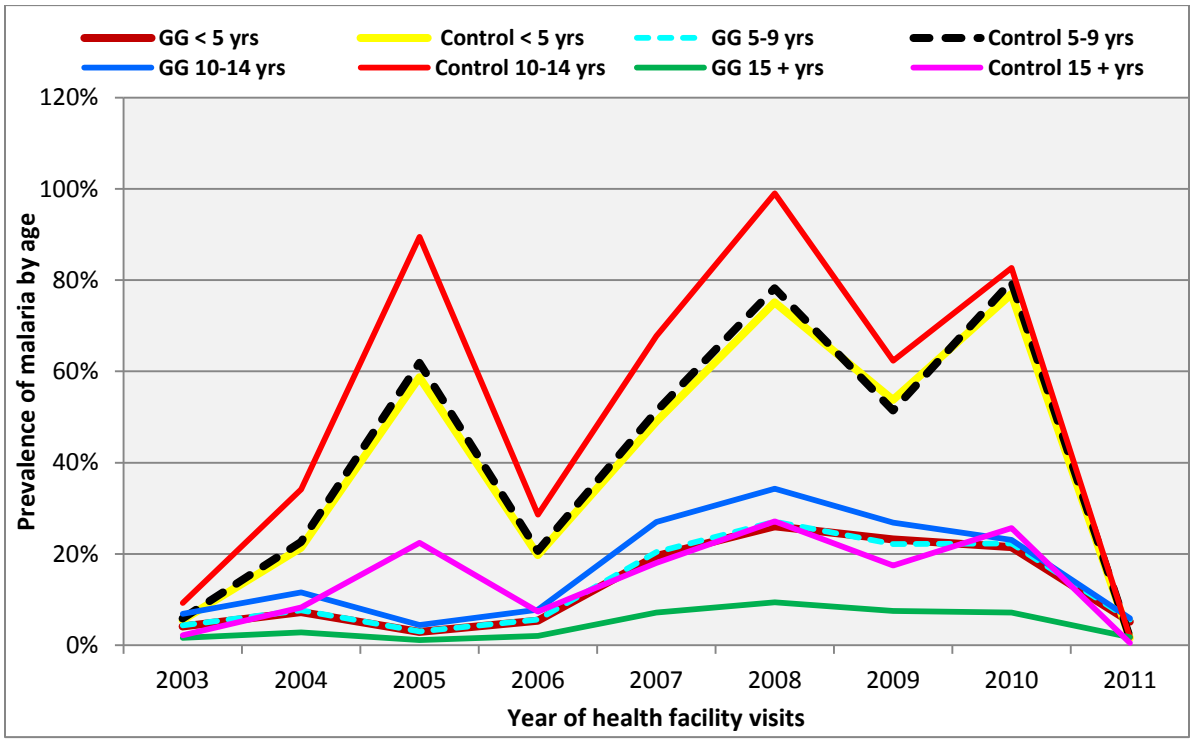

Figure 8 Prevalence of confirmed malaria by study site, age group and year, Jimma zone, Southwest Ethiopia

4.2. Dynamics of *P. falciparum* and *P. vivax* in a Micro-Ecological Setting, Southwest Ethiopia: Effects of Altitude and Proximity to a Dam

A total of 53,624 malaria episodes were recorded in the Gilgel Gibe HDSS site over a period of eight years of which 25,605 (47.7%) were records of clinical malaria and 28,019(52.3%) were confirmed malaria episodes. Of the positive cases, *P. falciparum, P. vivax and SM* constituted 60.4%, 33.6% and 6.0% respectively. Only those the records that the researcher managed to establish link with location identification of the Gilgel Gibe HDSS (10,443 episode records) were analyzed for spatial distribution of the diseases, while all the confirmed positive malaria records were considered in the temporal analysis.

The species composition of the geo-referenced malaria episodes were *P. falciparum* (69.2%), *P. vivax* (22.6%) *and SM* (8.2%). Generally, the contribution of *P. falciparum* was higher near the GGHD and proportion of *P. vivax* exhibited increment with the distance from the GGHD. Overall, 39.5% of the episodes were recorded in a distance of less than a kilometer radius of GGHD of which *P. falciparum* and *P. vivax* accounted for 81.4 % and 10.4% respectively. In the buffer zone from one to two kilometers radius, where a little bit more than a quarter of the malaria episodes wave recorded, *P. falciparum* contributed 68.2%, while the proportion of *P. vivax* was 22.5%. In the buffer zone from two to three kilometers radius, *P. falciparum* and *P. vivax* accounted for 62.7% and 27.8 % respectively. The proportions of *P. falciparum* in the buffer zones from three to four and four to five kilometers were 58.9% and 47.6%, while that of *P. vivax* were 34.8% and 48.3% respectively. Beyond five kilometers, the proportion of *P. falciparum* showed sharp shrink to 7.3% while that of *P. vivax* rose to 91.8% (Table 4).

Distribution of malaria episodes showed different patterns within species as well as among the buffer zones. Unlike *P. vivax* (18.1%), 46.4% of the *P. falciparum* and 39.4% of mixed species episodes were registered within a kilometer radius of the GGHD. The proportions of *P. falciparum* and *P. vivax* recorded in the buffer zone within range of one to two kilometers radius of GGHD were almost the same, 26.5% and 26.7% respectively.

On the other hand, only less than four in a hundred (3.6%) cases of *P. falciparum*, but about one in ten (19.5%) of the *P. vivax* episodes were recorded beyond two kilometers radius of the GGHD. The proportions of *P. falciparum* and *P. vivax* were similar for males and females where the former constituted nearly seven out of ten infections in both sexes (Table 4).

Only less than 1% of malaria episodes were registered to occur in the lower altitude of up to 1700 meter above sea level (masl). Majority of (79.2%) of the malaria episodes were registered in the altitude range of 1701-1800 masl where 80.2% of the *P. falciparum* and 74.3% of *P. vivax* malaria episodes were recorded and the composition of *P. falciparum* and *P. vivax* were 70.1% and 21.2% respectively. The next larger number (12.3%) of malaria episodes was registered in the altitude range of 1801-1900 masl. In this range, 11.9% and 14.3% *P. falciparum* and *P. vivax* were recorded and the proportions contributed by *P. falciparum* and *P. vivax* were 66.9% and 27.2% respectively (Table 4).

Table 4 Distribution of confirmed malaria episodes by *Plasmodium species*, distance from GGHD, altitude and sex , Jimma zone, southwest Ethiopia, September 2003 to August 2011

Varia-bles	Categories		Diagnosis (species of *Plasmodium*), N (%*)			Total
			P. falciparum	*P. vivax*	*Mixed*	
Distance from GGHD	< 1 km	N	3,250 (45.0)	427 (18.1)	336 (39.3)	4,013 (38.4)
		%	81.0	10.6	8.4	100.00
	1 to 2 km	N	1,890(26.2)	629(26.6)	261(30.5)	2,780 (26.6)
		%	68.0	22.6	9.4	100.00
	2 to 3 km	N	1,180 (16.3)	473 (20.0)	167(19.5)	1,820(17.4)
		%	64.8	26.0	9.3	100.00
	3 to 4 km	N	661(9.2)	395(16.7)	68(8.0)	1,124 (10.8)
		%	58.8	35.1	6.0	100.00
	4 to 5 km	N	243(3.4)	228(9.7)	21(2.5)	492(4.7)
		%	49.4	46.3	4.3	100.00
	> 5 km	N	2(0.03)	210(8.9)	2(0.2)	214(2.1)
		%	0.9	98.1	0.9	100.00
Altitude	≤ 1700 m	N	18 (0.3)	74 (3.1)	5 (0.6)	97 (0.9)
		%	18.6	76.2	5.2	100
	1701-1800 m	N	5,796 (80.2)	1,755 (74.3)	716 (83.7)	8,267 (79.2)
		%	70.1	21.2	8.7	100
	1801-1900 m	N	857 (11.9)	348 (14.7)	77 (9.0)	1,282 (12.3)
		%	66.9	27.2	6.0	100
	1901-2000 m	N	302 (4.2)	115 (4.9)	37 (4.3)	454 (4.4)
		%	66.5	25.3	8.2	100
	2001-2100 m	N	137 (1.9)	35 (1.5)	15 (1.8)	187 (1.8)
		%	73.3	18.7	8.0	100
	>2100 m	N	116 (1.6)	35 (1.5)	5 (0.6)	156 (1.5)
		%	74.4	22.4	3.2	100
Age (year)	< 5	N	651 (9.0)	258 (10.9)	85 (9.9)	994 (9.5)
		%	57.7	36.1	6.3	100
	5-9	N	968 (13.4)	345 (14.6)	114 (13.3)	1,427 (13.7)
		%	60.6	32.5	6.9	100
	10-14	N	1,098 (15.2)	370 (15.7)	116 (13.6)	1,584 (15.2)
		%	64.0	29.6	6.3	100
	15 +	N	4,509 (62.4)	1,389 (58.8)	540 (63.2)	6,438 (61.7)
		%	61.5	30.9	7.7	100
Sex	Male	N	4,032 (55.8)	1,360(57.6)	450 (52.8)	5,842(56.0)
		%	69.0	23.3	7.70	100.00
	Female	N	3,194 (44.2)	1,002 (42.4)	404 (57.2)	4,600(44.1)
		%	69.4	21.8	8.8	100.00
Total		**N**	7,226 (100)	2,362 (100)	855 (100)	10,443 (100)
		%	61.3	31.3	7.3	100

* Percentage within diagnosis

As distance increases from the GGHD, the occurrence of *P. falciparum* malaria increases up to five km. In the buffer zone 1 to 1.99 km (2nd buffer), *P. falciparum* about four times more likely to occur compared to the buffer zone with in one km radius of GGHD, which is the reference buffer zone. In the 3rd buffer zone (3 to 3.99 km), the occurrence of *P. falciparum* was more than five times likely to occur compared to the reference buffer zone. In the 4th and 5th buffer zones, *P. falciparum* was about four times and three times respectively more likely to occur compared to the reference buffer zone. Starting from five km, the occurrence of *P. falciparum* malaria was not significantly different from that of the reference buffer zone.

However, increasing altitude showed both positive and negative correlations with the occurrence of *P. falciparum* malaria and the correlations were significant, except altitude from 1801 to 1900 masl compared to the reference altitude of up to 1700 masl. In the altitude range between 1701 to 1900 masl, the occurrence of *P. falciparum* was negatively correlated compared to the reference altitude. On the other hand, above 1900 m, there was positive and steadily significant increase of *P. falciparum.* In the altitude ranges from 1901-2000 m, 2001-2100 and above 2100 masl, *P. falciparum P. falciparum* 1.6 times, 2.5 times and 2.6 times more likely to occur, compared to altitude up to 1700 masl. The risk of *P. falciparum* was significantly higher among male and children in the age range ten to fourteen years, when the effects of distance from the GGHD and altitude controlled (Table 5).

Table 5 Influence of proximity to a dam and altitude on *P. falciparum* malaria in GGHD site, Jimma zone, southwest Ethiopia September 2003 to August 2011

Variables	Categories	IRR	S. E.	95% C.I. Lower	Upper
Buffer zones relative to GGHD	< 1 km (1st buffer)	1			
	1-1.99 km (2nd buffer)	3.82	0.07	3.68	3.96
	2-2.99 km (3rd buffer)	5.10	0.12	4.88	5.34
	3-3.99 km (4th buffer)	3.73	0.10	3.53	3.93
	4-4.99 km (5th buffer)	2.97	0.13	2.72	3.24
	≥5 km (6th buffer)	1.04	0.15	0.78	1.37
Altitude in meters	≤ 1700	1			
	1701-1800	0.03	0.01	0.02	0.04
	1801-1900	0.93	0.17	0.65	1.33
	1901-2000	1.61	0. 30	1.12	2.31
	2001-2100	2.51	0.47	1.74	3.63
	≥ 2101	2.64	0. 50	1.82	3.82
Age (year)	< 5	1			
	5-9	1.05	0.04	0.98	1.12
	10-14	1.10	0.04	1.03	1.17
	15+	1.04	0.03	0.99	1.10
Sex	Male	1			
	Female	0.96	0.01	0.93	0.99

On the other hand, with distance increment from the GGHD, the occurrence of *P. vivax* increases significantly keeping the effects of altitude, age and gender constant. The *P. vivax* malaria occurrence in the 2nd, 3rd , 4th , 5th and 6th buffer zones were 9.8 times, 13.6 times, 11.9 times, 52.0 times and 68.8 times more likely to occur compared to the occurrence of *P. vivax* within one kilometer radius of the GGHD.

However, increasing altitude was negatively and significantly associated with the occurrence of *P. vivax* malaria. The decrement of *P. vivax* with altitude was insignificant and the reduction of *P. vivax* in the altitudinal range of 1701-1800, 1801-1900, 1901-2000, 2001-2100 and above 2100 masl was 98.5%, 56.4%, 36.0%, 49.1% and 46.1% respec-

tively compared to the altitude up to 1700 masl. The risk of *P. vivax* exhibited decrement significantly as age increases and the risk was higher in female than males, when the effects of distance from the GGHD, age and altitude controlled (Table 6).

Table 6 Influence of proximity to a dam and altitude on *P. vivax* malaria in GGHD site, Jimma zone, southwest Ethiopia, September 2003 to August 2011

Variables	Categories	IRR	S. E.	95% C.I.	
				Lower	Upper
Buffer zones relative to GGHD	< 1 km (1st buffer)	1			
	1-1.99 km (2nd buffer)	9.82	0.32	9.22	10.47
	2-2.99 km (3rd buffer)	13.56	0.50	12.61	14.58
	3-3.99 km (4th buffer)	11.94	0.49	11.02	12.93
	4-4.99 km (5th buffer)	52.00	2.10	48.03	56.29
	≥5 km (6th buffer)	68.72	3.46	62.26	75.85
Altitude in meters	≤ 1700 m	1			
	1701-1800	0.02	0.001	0.02	0.01
	1801-1900	0.44	0.03	0.38	0.50
	1901-2000	0.64	0.05	0.55	0.75
	2001-2100	0.51	0.06	0.41	0.64
	>2100 m	0.54	0.06	0.43	0.68
Age (years)	< 5	1			
	5-9	0.91	0.04	0.83	0.99
	10-14	0.84	0.04	0.78	0.92
	15 +	0.89	0.03	0.83	0.95
Sex	Male	1			
	Female	1.04	0.02	1.00	1.09

Overall, there was reduction of about 70 % and 60% of malaria episodes in the years 2004/5 and 2005/6 respectively, compared to that of 2003/4. However, since 2006/7 increment of malaria episodes was evident up to 2010. In 2006/7, the malaria episode increased by about 50% compared to 2003/4. In the following three years, the increment of malaria episodes was 2.3 times, 2.9 times and 4.1 times more likely higher in the years 2008/9, 2009/10 and 2011 compared to the observed episodes of malaria in the year 2003/4. In the year 2011, the malaria episodes showed reduction of 14%, which was statistically insignificant.

On average, *P. vivax* was 54% lower than *P. falciparum* over the study period. The rate of *P. vivax* increments were 130% and 40% in the years 2004/5 and 2005/6 respectively compared to *P. falciparum* episodes of those years. In the years 2006/7, 2007/8 and 2010/2011 there were 60% *P. vivax* rate increments compared to *P. falciparum* during the same time. On the other hand, in the years 2008/9 and 2009/10, there were reductions of *P. vivax* episodes rate by 10% and 16% respectively, though the reduction was insignificant in 2008/9 (Table 7).

Table 7 Temporal pattern of malaria in GGHD site, Jimma zone, southwest Ethiopia, September 2003 to August 2011

Plasmodium species	**Year**	**IRR**	**Std. Err.**	**(95% C. I.)**	
All positive	2003/4	1			
	2004/5	0.30	0.02	0.27	0.34
	2005/6	0.40	0.02	0.36	0.44
	2006/7	1.15	0.04	1.07	1.24
	2007/8	2.26	0.08	2.11	2.41
	2008/9	2.87	0.09	3.00	3.06
	2009/10	4.08	0.13	3.84	4.34
	2010/11	0.96	0.04	0.89	1.04
P. vivax in reference to *P. falciparum*	During the whole period	1			
		0.48	0.02	0.43	0.52
Species interaction	2003/4	1			
	2004/5	2.30	0.20	1.95	2.72
	2005/6	1.41	0.12	1.19	1.67
	2006/7	1.57	0.10	1.39	1.78
	2007/8	1.59	0.09	1.42	1.77
	2008/9	0. 90	0.05	0.80	1.00
	2009/10	0.84	0.05	0.76	0.94
	2010/11	1.61	0.10	1.42	1.83

4.3. Correlation of climate variability and malaria: a retrospective comparative study, Jimma zone Southwest Ethiopia

A total of 99,206 confirmed malaria cases were recorded over eight years (September 2003 to August 2011) period in the study sites. More than two-third (71.8) of the cases was from control site and 28.2% of them were from Gilgel-Gibe (GGHD) site. In spite of inter annual variations, proportion of *P falciparum* slightly increased over time in GGHD. However, the P. falciparum proportion significantly decreased relative to the *Plasmodium vivax* in the control sites. Figure 9 shows the relationship between mean monthly rainfall and confirmed malaria prevalence over the eight years. The rainfall pattern in the GGHD site showed several rises that lasted for short durations, whereas that of the control area exhibited a gradual rise and relatively minimal variations. At the GGHD site, the major peaks of malaria prevalence observed following the peaks of rainfall.

In the control site, the peaks of malaria prevalence in some years just coincided with the peaks of rainfall and the pattern of rainfall was relatively less fluctuated and almost continuous in quarters of the year. Between December 2007 and March 2008, rainfall reached highest peak and the major malaria prevalence peak noticed after the rainfall peak. It is evident from the linear trend line that malaria prevalence increased more in the GGHD site than in the control site irrespective of the higher malaria prevalence observed in the control site over the whole time period considered (Fig 9).

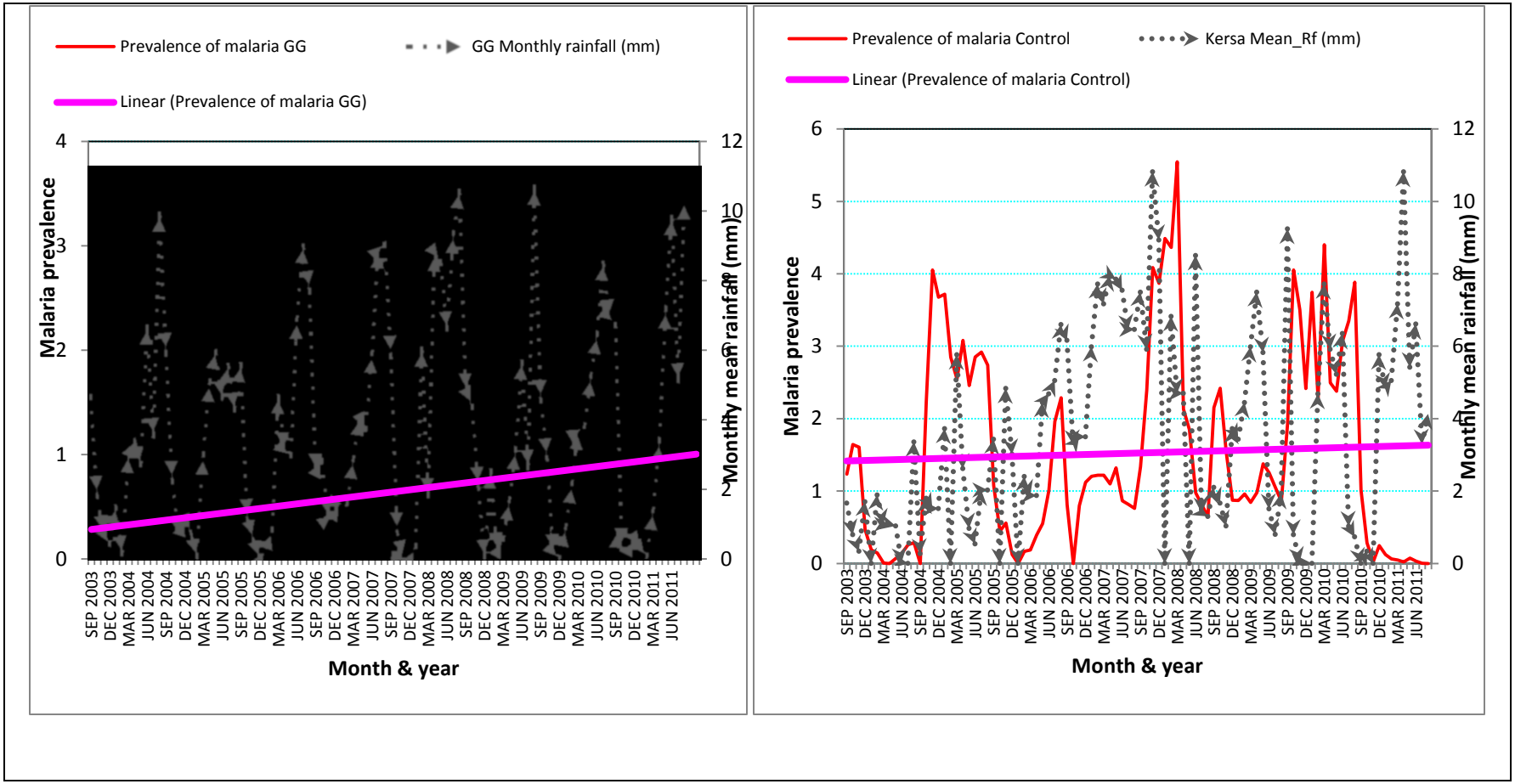

Figure 9 Malaria prevalence and monthly mean rainfall by quarter and year, Jimma zone, Southwest Ethiopia, September 2003-August 2011

Monthly mean rainfall and number of monthly malaria cases showed negative correlation at 1 month lag, but positive correlation at lags of 2 to 4 months. The correlation increased as number of lags increased up to the fourth month although the positive correlation of rainfall with the number of malaria was insignificant at all the lags. Monthly mean relative humidity showed positive correlation with number of malaria up to 4 months and the strength of correlation increased as the number of lags increased. There was significant correlations at lags of 3 (P = 0.02) and 4 (P = 0.03) months. Monthly mean maximum temperature and the number of malaria cases showed negative, but insignificant correlation up to 4 months lags. Again, monthly mean minimum temperature exhibited a negative correlation with number of malaria cases up to lags of 2 months but positive correlation at lags of 3 and 4 months. The correlation was of the incremental nature with number of lag months; however, the correlation was weak and insignificant (Table 8).

Table 8 Correlation between average monthly malaria cases and mean monthly climate variables by study sites, Jimma zone, Southwest Ethiopia, September 2003-August 2011

Monthly mean Climate variables	Lag-months	Gilgel-Gibe r	Control r	Overall r
Rainfall	0 Month	0.0060	-0.1959	-0.076
	1 Month	0.1278	-0.1473	-0.003
	2 Months	0.3589	-0.1495	0.065
	3 Months	0.3270	-0.0806	0.078
	4 Months	0.2304	0.0494	0.108
Relative humidity	0 Month	0.0133	-0.2154	0.006
	1 Month	0.1591	-0.1099	0.086
	2 Months	0.4182	-0.0381	0.133
	3 Months	0.2820	0.0789	0.171
	4 Months	0.2174	0.1184	0.157
Maximum temperature	0 Month	-0.0983	0.1723	-0.020
	1 Month	-0.2044	0.0966	-0.072
	2 Months	-0.2350	0.0203	-0.136
	3 Months	-0.2233	-0.0894	-0.130
	4 Months	-0.1874	-0.1099	-0.116
Minimum temperature	0 Month	-0.261	-0.1108	-0.123
	1 Month	-0.0808	-0.0611	-0.052
	2 Months	0.0191	-0.0535	-0.031
	3 Months	0.1135	0.0441	0.001
	4 Months	0.1676	0.1027	0.039

4.4. Predictors of Long-Lasting Insecticide Treated Bed Nets Ownership and Utilization

A total of 2,373 (100%) individuals responded to the household survey. Half of them (1,187) were from Gilgel-Gibe (GGHD) and the other half (1,186) were from the control villages corresponding to 5,946 (49.8%) and 5,984 (50.2%) household members resided in the two study sites respectively having similar sex compositions. As indicated in table 10 (page 65), majority of the heads of households were married in both sites (86.5% GGHD vs 88.8% control); close to nine percent of household heads reported from both study sites that they were widowed and about one percent were divorced.

About three-fourth of the heads of households (77.4% GGHD and 73.4% controls) did not have any formal education. Those attended elementary (grades 1-8) constituted 11.5% and 17.2% from GGHD and control sites respectively. Those heads of households who attended grade nine or above constituted below three percent of the respondents in both study sites. With regard to occupational status, most of them were farmers (65.3% of the GGHD and 89.2% of the control). Concerning accessibility to health facilities in terms of distance, the control population seems better as all of them reported to be within an estimated distance of 2 kilometers of the health facilities in contrast to the GGHD HHs of which 19.2% reported to live more than two kilometers away from health facilities.

There was a similarity with regard to accessibility to vehicle transportation where about two-third (60.4% GGHD and 62.2% control) of the study populations reported to be inaccessible to all-weather roads to reach health facilities. The average age of household members was about 21 years for both populations. Significant differences were not seen between the two populations regarding household size, average age of the populations, perceived monthly expenditure, number of farm animals owned, and amount of grain produced in one year preceding the survey. However, differences were observed pertaining to age of household heads where that of GGHD was higher by about two years; regarding to reported monthly income and relative wealth index, the control population responded to have been better off (Table 1 of paper four).

The overall ownership of LLINS among the study populations was 56.6% (66.3% of GGHD & 46.8% of control) whereas 43.4% (33.7% of GGHD & 53.2% of control) of them reported that they didn't have any net. Higher proportion of the households from GGHD site reported to have at least one LLIN compared to control villages (OR =2. 2, P <0.001) (Table 11). Concerning the number of LLINS owned, more households from GGHD reported to have only one LLINS than two or more in contrast to the control households (OR = 2.1, P < 0.001) and close to two-third of the GGHD households got the LLINS by paying, whether subsidized or not, unlike the control households where half of them obtained the LLINS freely (OR = 0.63, P < 0.001).

The mean number of LLINS owned by GGHD and control households were 1.6 and 1.8 respectively with a mean difference of -0.26 (95% CI = - 0.34, -0.19; SE = 0.04). But, less respondents from GGHD replied that they had perceivably sufficient LLINS for their family members compared to control villages (OR = 0.24, P <0.001); however, less number of the GGHD respondents reported intention to have additional LLINS in the future compared to respondents from control village (OR = 0.61) though the difference was not statistically significant (P = 0.22).

Unlike their previous experience, majority (95.7%) of the GGHD respondents were expecting to receive LLINS for free, whereas three-fourth of the control respondents reported that they hope to obtain free LLINS to suffice the LLINS need of their family members in the future. Only a small proportion (4.2% of GGHD & 23.3% of control) of them had intention to buy LLINS to suffice their families. The average suggested cost of LLINS was 17.0 Birr (≈ $ 0.9) with median 10.0 Birr (lower & upper quartiles were 6.0 & 20.0 respectively).

The reported utilization rate of LLINS was better among the control households than that of GGHD households. Of those households who had at least one LLIN, more respondents from GGHD reported that at least a person from their family members didn't use LLINS compared to control population (OR=2.8, P <0.001). Similarly, the GGHD residents were twice less likely (OR = 0.48, P < 0.001) to have had slept under LLINS in previous night and less than five times likely (OR = 0.19, P < 0.001) to have had slept under LLINS in the last month preceding the survey compared to respondents from control site (Table 9).

Table 9 Comparison of Ownership and Utilization of Long-lasting insecticidal net between Gilgel-Gibe and control villages, Southwest Ethiopia, November 2012

Long lasting insecticidal nets (LLINs)		Gilgel-Gibe villages		Control villages		OR (95% CI)
		N	%	N	%	
Ownership of LLINs (at least one)	Yes	787	66.3	555	46.8	2.2 (1.9-2.6)*
	No	400	33.7	631	53.2	
Number of LLINs owned	One	418	35.2	194	16.4	2.1 (1.9 -3.8)*
	≥ Two	369	31.1	361	30.4	
Source of LLINs	Free	307	39.0	279	50.3	0.63 (0.51 – 0.79)*
	Bought	480	61.0	276	49.7	
Used last night (those who had ≥ 1)	Yes	760	60.1	778	76.1	0.47 (0.39-0.57)*
	No	505	39.9	245	23.9	
Used last Month (those who had ≥ 1)	Yes	759	60.0	910	89.0	0.19 (0.15-0.23)*
	No	506	40.0	113	11.0	
Any one from the family member who didn't use LLINs	Yes	454	57.7	182	32.8	2.8 (2.2- 3.5)*
	No	333	42.3	373	67.2	
Sufficient of LLINs for the family members (those who have ≥ 1)	Yes	329	41.8	415	74.8	0.24 (0.19-0.31)*,
	No	458	58.2	140	25.2	
Intention to have LLINs in the future	Yes	841	97.9	762	98.7	0.61 (0.28, 1.3)*
	No	18	2.1	10	1.3	
Mechanisms of having LLINs	Bought	35	4.2	178	23.3	1.6 (0.2-13)
	Free	805	95.7	577	75.6	11.2 (1.4 – 89.5)*

* & ** indicate significances at 0.05 & 0.001 respectively

Factors associated with number of LLINs owned were also assessed using multinomial logistic regression. Variables like gender, educational status, and occupational status of household heads did not show a significant association with ownership of LLINS. On the other hand, variables such as age

of household heads, household relative wealth index (RWI), distance to nearest health facilities and accessibility to transportation (all weather roads) showed a significant association with the ownership of the LLINs. The chance of having LLINs was positively associated with age of household heads. Particularly, the probability of having two or more LLINs was positively related to age of the household heads. Those households with heads aged 60 or above years were nearly twice more likely to have one LLIN and more than three-folds likely to have two or more LLINs compared to families with less than 30 years heads of households.

Families with heads of households who were together with their spouses were closely twice more likely to have two or more LLINs than those families whose heads were single, widowed or separated. Household relative wealth index didn't show chance difference of having one LLIN among the households of different wealth index quantile categories. On the other hand, the probability of having two or more LLINs was found to be directly associated with the household wealth indices. Those households in the fifth quantile category were 3.3 and 1.7 times more likely to have two or more LLINs compared to those households in the first and second quantile categories respectively.

Households within one kilometer distance to nearest heath facilities were 12 times more likely to have one LLIN and 45 times to have two or more LLINs compared to those households beyond two kilometers from health facilities. Again, those households found between distances of one to two kilometers were seven times more likely to have one LLIN and nearly 12 times to have two or more LLINs compared to those households beyond two kilometers from health services. Similarly, those families who had reportedly accessibility to transportation were 1.5 times more likely to have one LLIN and twice more likely to have two or more LLINs as compared to those families who did not have access to transportation (Table 10).

Table 10 Factors associated with number of long lasting insecticide-treated bed nets owned, South-west Ethiopia, November 2012

Variables	Variables Categories	Total	Owned ≥ 1 LLINs		Owned One LLIN	Owned ≥ 2 LLINS
		No (%)	N (%)	AOR (95% CI)	AOR (95% CI)	AOR (95% CI)
Age of HH Heads	<30 years	356 (15.0)	165 (46.3)	0.4 (0.3, 0.6)**	0.6 (0.4, 0.9)*	0.3 (0.2, 0.4)**
	30-39 years	710 (29.9)	401 (56.5)	0.7 (0.5, 0.9)**	0.8(0.6, 1.2)	0.6 (0.4, 0.9)**
	40-49 years	548 (23.1)	306 (55.8)	0.7 (0.5, 0.9)*	0.7 (0.5, 1.0)	0.7 (0.5, 0.98)*
	50-59 years	358 (15.1)	218 (60.9)	0.8 (0.8,1.5)	0.9 (0.5, 1.3)	0.8 (0.6, 1.1)
	≥ 60 years	401(16.9)	252 (62.8)	1	1	1
Marital status	Married	2080 (87.7)	1186 (57.0)	1.3 (0.9, 1.9)	1.0 (0.8,1.5)	1.7 (1.1, 2.5)*
	Not in marriage	293 (12.3)	156 (53.2)	1	1	1
HH RWI	Poorest	475 (20.4)	241 (50.7)	0.5 (0.4,0.7)**	0.8 (0.5, 1.1)	0.3 (0.2, 0.3)**
	Poor	461(19.8)	256 (55.5)	0.7(0.5, 0.99)*	1.0 (0.7, 1.5)	0.6 (0.4,0.8)**
	Middle	466 (20.0)	275 (59.0)	0.9 (0.7, 1.2)	1.1 (0.8, 1.7)	0.8 (0.6,1.1)
	Less poor	455 (19.5)	273 (60.0)	0.9 (0.7, 1.2)	1.0 (0.7, 1.5)	0.8 (0.6, 1.1)
	Least poor	472 (20.3)	268 (56.8)	1	1.	1
Distance to the health institution	< 1 km	1655 (69.7)	1051 (63.5)	21.9 (14.9, 32.2)**	12.4 (8.0,19.2)**	45.1 (24.8, 82.1)**
	1-2 km	490 (20.6)	244 (49.2)	8.5 (5.7, 12.7)**	7.0 (4.4,11.0)**	11.8 (6.3, 21.9)**
	> 2 km	228 (9.6)	47 (20.6)	1	1	1
Accessible to transport	Yes	918 (38.7)	621 (67.6)	2.1 (1.8, 2.5)**	1.5(0.8, 1.3)	2.1(1.6, 2.6)**
	No	1455 (61.3)	721 (49.6)	1	1	1
Residence	GGHD area	1187 (50.0)	787(66.3)	1.8 (1.5, 2.2)**	7.0 (5.5, 9)**	4.3 (3.4, 5.5)**
	Control area	1186 (50.0)	555 (46.8)	1	1.	1.
HH size	≤3	638 (26.9)	338 (53.0)	0.99 (0.7, 1.3)	3.4 (2.3, 5.0)**	0.3 (0.2, 0.5)**
	4-6	1122 (47.3)	654 (58.3)	1.1(0.9, 1.4	2.1(1.5, 3.0)**	0.9 (0.7, 11)
	≥7	613 (25.8)	350 (57.1)	1	1	1

* & ** indicate significances at 0.05 & 0.001 respectively

Residents of GGHD reported to have 7 times and four times more likely to have one LLIN and two or more LLINs respectively than control residents. Finally, household size was found to be a predictor of the number of LLINs owned. Households with three or less members were more than 3 times more likely to have one LLIN but 70% less likely to have two or more LLINs. Households having family members from four to six were twice more likely to have one LLIN compared to those house-

holds with seven or more family members; however, there was a significant difference of having two or more LLINs between them (Table 10 above).

Regarding utilization of LLINs, factors such as gender, educational and occupational status of household heads were not related to utilization of LLINs. On the other hand, age, marital status of household heads, relative wealth index, and distance to nearest health facilities, accessibility to transport and residence and household size were significantly associated with the utilization of LLINs. As age of household heads increased, utilization of LLINs showed steady decline. Households with heads less than 30 years and those with household heads of age range from 30 to 49 years reported to have used LLINs; respectively, more than three times and about twice likely compared to those households with 60 years or older household heads. However, a significant difference was not seen between households with household heads age 50 years and above.

Households who were in marriage reported more than three times utilization of LLINS compared to households whose heads were widowed, divorced or separated. Household relative wealth index was found to be an influential predictor of utilization of LLINS. Wealthy households reported more utilization of LLINs. Those wealthiest families were more than three times more likely to have used LLINS than very poor and poor families. Again, the least poor households were 2.5 and 1.7 times more likely to report LLINS utilization compared to those in the middle and less poor families respectively.

Households within one kilometer radius of health facilities were 17.5 times and those within one to two kilometers away from health facilities 6.7 times more likely to use reportedly LLINS. On the other hand, households in the control villages were twice more likely use LLINS compared to households around Gilgel-Gibe Dam. Another influential predictor was household size where those households with three or less members reported more utilization of LLINS compared to households with large family sizes (Table 11).

Table 11 Factors associated with Long-lasting insecticide treated bed net Utilization Jimma zone, Southwest Ethiopia, November 2012

Variable	Categories	Used LLINs N (%)	AOR (95% CI)
	< 30 yrs	148 (69.8)	3.5 (1.6, 7.6)**
	30-39 yrs	461 (69.5)	2.1 (1.3, 3.6)**
Age head of household	40 -49 yrs	403 (69.5)	1.8 (1.1, 3.0)*
	50 - 59 yrs	253 (64.9)	1.4 (0.8, 2.4)
	≥ 60 yrs	255 (63.0)	1
Gender of household head	Male	1313 (68.5)	1.1 (0.9, 1.5)
	Female	207 (62.3)	1
Marital status of household head	Married	1384 (67.9)	3.6 (1.0, 12.4)*
	Not in marriage	133 (64.3)	1
	None	1126 (67.7)	1 (0.5, 2.0)
	Read and write	148 (72.9)	1.2 (0.6, 2.7)
Educational status of household head	Elementary (1.4)	128 (60.7)	0.6 (0.3, 1.2)
	Elementary (5-8)	75 (64.7)	0.6 (0.3, 1.5)
	Grade ≥ 9	40 (76.9)	1
	Farmer	893 (49.0)	0.5 (0.2, 1)
Occupational status of household head	Housewife	319 (84.4)	0.6 (0.3, 1.2)
	Daily laborer	12 (46.2)	0.8 (0.3, 2.4)
	Others [1]	41 (67.2)	1
	Very poor	182 (55.6)	0.3 (0.2, 0.6)**
	Poor	255 (63.3)	0.3 (0.2, 0.5)**
RWI of household	Middle	310 (67.5)	0.4 (0.3, 0.7)**
	Less poor	345 (70.7)	0.6 (0.4, 0.9)
	Least poor	395 75.7	1
Distance to health facilities	< 1 km	942 (50.9)	14.3 (7.7, 26.8)**
	1 to 2 km	260 (69.1)	6.2 (3.2, 11.8)**
	2 km	63 (100)	1
Access to transport	Yes	637 (57.2)	0.3 (0.21, 0.33)**
	No	880 (77.8)	1
	Gilgel-Gibe Villages	742 (60.3)	0.5 (0.3, 0.7)**
Residence	Control Villages	778 (76.3)	
	1-3 members	288 (69.4)	1.7 (1.2, 2.3)**
HH size	4-6 members	721 (66.3)	1.1 (0.9, 1.4)
	7 & above	511 (68.5)	1

[1] Others include: government employees (1.1%), merchants (0.8%), self employed (0.7%) & students (0.3%);

* & ** indicate significances at 0.05 & 0.001 respectively.

4.5. Prevalence of malaria in the Community where District-based Model and Community-based Model Indoor Residual Sprays applied

A total of 2269 individuals were included in the blood survey. Overall, there were 17 (0.7%) positive cases of malaria identified from the total 2269 tested individuals. Malaria prevalence was 7.0 per 1000 population in the surveyed population with 0.7% & and 0.8% among males and females respectively. The positivity rate was similar across age groups although the prevalence seemed higher (1.2%) among children less than five years of age and yet, the difference was not statistically significant.

All of the malaria positive individuals were from Gilgel-Gibe site where the District-based IRS model was implemented, implying the actual prevalence was 1.7% (17/1012) among the GG residents. Regarding the proportion of Plasmodium species composition, *P. falciparum* constituted 58.8%, *P. vivax* was 41.2 and only a case was positive for both *P. falciparum* and *P. vivax*. Malaria case was not found in the economically least poor households in the studied villages, even though malaria prevalence did show neither increasing nor decreasing patterns among other categories of relative wealth index of the households (Table 12).

Table 12 Distribution of blood film results by characteristics of participants, Jimma zone Southwest Ethiopia, November 2012

Variables		Negative	All positive			P. vivax		P. falcipa-rum		
		N	%	N	%	N	%	N	%	Total
Age	< 5 yrs	318	98.8	4	1.2	1	0.3	3*	0.9	322
	5-9 yrs	479	99.4	3	0.6	2	0.4	1	0.2	482
	10-14	337	99.7	1	0.3	1	0.3	0	0.0	338
	≥15 yrs	1118	99.2	9	0.8	3	0.3	6	0.5	1127
	Total	**2252**	**99.3**	17	0.7	**7**	**0.3**	**10***	**0.5**	**2269**
Sex	Male	1091	99.3	8	0.7	3	0.3	5	0.5	1099
	Female	1161	99.2	9	0.8	4	0.3	5*	0.4	1170
	Total	**2252**	**99.3**	17	0.7	**7**	**0.3**	**10**	**0.5**	**2269**
Residence:	< Km	449	98.7	6	1.3	4	0.9	2*	0.4	455
	> Km	696	98.4	11	1.6	3	0.4	8	1.1	707
	Total	**2252**	**99.3**	**17**	**0.7**	**7**	**0.3**	**9**	**0.4**	**2269**
Insecticide used for IRS	BC*	995	98.3	17	1.7	7	0.7	10*	1.0	1012
	DM *	1257	100	-	-	-	-	-	-	1257
	Total	**2252**	**99.3**	**17**	**0.7**	**7**	**0.3**	**10**	**0.5**	**2269**
Mode of IRS	DB	995	98.3	17	1.7	7	0.7	10*	0.9	1012
	CB	1257	100	-	-	-	-	-	-	1257
	Total	**2252**	**99.3**	**17**	**0.7**	**7**	**0.3**	**10**	**0.5**	**2269**
HH RWI	Very poor	286	98.6	4	1.4	3	0.3	1	0.3	290
	Poor	291	99.0	3	1.0	1	0.7	2	0.7	294
	Middle	355	99.4	2	0.6	1	0.3	1	0.3	357
	Less poor	344	97.7	8	2.3	2	1.7	6	1.7	352
	Least poor	369	100.	-	-	-	-	-	-	369
	Total	**1645**	**99.0**	**17**	**1.0**	**7**	**0.4**	**10**	**0.6**	**1662**

** BC = Bendiocarb; DM = deltamethrin; CB = Community-base model; DB = District-based model; HH = household; P. falciparum = Plasmodium falciparum; P. vivax = Plasmodium vivax; RWI = relative wealth index*

5. Discussions

5.1. Analysis of Trend of Malaria Prevalence in Southwest Ethiopia:

This retrospective health facility based study assessed the trend of malaria over a period of eight years along climatic variables. The essence of the trend analysis was to estimate and compare the prevalence of malaria, identify possible shift of *Plasmodium species* compositions over time in the two localities using data of the local health facilities. The study considered only key individual characteristics (age and sex), date of diagnosis, diagnosis outcome and address of the cases in an attempt to minimize the usual limitations of secondary data such as incompleteness of information. Moreover, as the study dealt with a relatively large set of data, so that the appearance of findings due to chance is expected to be minimized. Thus, the retrospective health facility-based study is believed to have presented the distribution of malaria over a period of eight years by person, place, time, and composition of *Plasmodium* species.

Irrespective of the scaling-up of long-lasting insecticide-treated bed nets (LLINs) distribution since 2005 (80), the steadily increased number of cases from 2006 to 2008 might be due to resistance development by malaria vector mosquitoes to DDT and Malathion that had been in use for IRS for about half a century until malaria vector resistance to DDT was detected in 2007 (87, 206, 207) . The increment of malaria cases in GGHD site was still by far below that of the control site despite the earlier report of a study (132), which indicated higher risk of malaria infection among children who lived within three kilometer radius of the GGHD compared to those children lived eight to ten kilometers away from the dam. However, a more recent report of longitudinal study of the same area showed that there was no significant malaria risk difference between children who lived in villages near the dam and those who lived away from it and malaria was reported to be highly seasonal driven in the area (116). This implies that s malaria risk due to the dam construction was not significantly evident over the long period as far as interventions are in place like other malarious areas.

On the other hand, the sharp decline of the number of malaria cases after 2009 in the study sites could possibly be due to the replacement of old LLINs in 2009, followed by shifting of insecticide used for IRS in 2010 to deltamethrin or bendiocarb insecticides (87). The coincidence of interventions and drastic drop of malaria is in line with report of other studies (47, 81, 161, 208-211), which

revealed also resurgences of the disease following delayed or interrupted interventions. This strengths the need for the effective combined intervention methods using IRS with potent insecticides and LLINs as evidenced by different studies (174, 212, 213), as well as the need for close monitoring the possible insecticide resistance of mosquitoes.

The current study shows that slightly more males were affected than females. This finding is similar to other findings (178, 214-220), but this is different from a study done in Nigeria that reported more infection among females and similar susceptibility in all age groups (221). However, the prevalence of malaria in the children less than fifteen years old was by far higher than reported by another study (222). The fact that children aged from ten to fourteen years were more affected than those below ten years suggests not susceptibility difference but exposure difference, which is in agreement with finding of a local study that old age children were found to be disadvantaged ones among family members in the use of LLINs (223-225). Similarly, other studies reported more infections among children (33, 226-228) than older age groups, but other studies reported more susceptibility in adult age groups (216, 229-232). The latter might be due to other factors, such as migrations, living and working conditions (233, 234) that exposes adults for more infections.

On the other hand, reporting by absolute number or proportion of cases can also mislead to improper interpretation and conclusion unless the denominator of each age category is considered. For instance, in the current finding (Table 2) shows that the proportion of adult cases is higher by many folds than that of children; however, consideration of prevalence (Figure 6), which takes into account respective denominators, points out that the children were actually the most affected ones. This implies the need to consider appropriate denominators while analyzing the extent of malaria burden among different segments of a population.

The findings of this study is in agreement with other studies (235, 236) that the prevalence of *P. falciparum* showed more pronounced seasonal fluctuations, whereas *P. vivax* exhibited less variability with season in the GGHD site, possibly due to the relapse nature of the disease (237-239) that maintains the chain of the transmission resulting in less season variations in its trend. Another study reported also differential distribution of the two species by seasons (240). However, in another study

(230), *P vivax* showed more variability compared to *P. falciparum*, although there has been similarity in the overall dominance of the *P. falciparum*, which has also been indicated by other studies as well (241-243) but, another study (244) reported that both species showed significantly variable distribution during different seasons. In the control site , the seasonal patterns of *P. falciparum* and *P. vivax* were more or less similar, except during major peak malaria transmission seasons, which occurs in the form of epidemics.

Regarding to secular patterns, the continuous decline of *P. falciparum* proportion observed in the control area, where the proportion was generally similar over time in the GGHD site, is different from the another previous local study (45) which reported significant rise of the *P. falciparum* proportion and decrease of *P vivax* proportion. But, it is similar with another study which reported area specific shift from a preponderance of *P. falciparum* to *P. vivax* and vice versa (38). The proportion of *P. vivax* malaria in the control site constantly increased in relation to *P. falciparum* over the study period, which might have contributed to the higher level of malaria prevalence in the control site. This is consistent with other studies that transmission of malaria due to *P. vivax* become higher and changed the epidemiology of malaria (234, 245, 246) due to its wide spread and its relapsing nature (237, 247-252).

Overall, the proportion of *P. falciparum* noticed in the present was less than the report of some previous local studies (80, 178, 253); however, it was similar with the findings of health facility-based studies in Ethiopia (150, 254). Yet, the proportion of *P. falciparum* was higher by far than findings of community-based surveys (150, 213, 246). This could be due to the fact that in the community based studies, less severe cases who usually don't seek out actively medical care and asymptomatic cases of *P. vivax* (255) can be identified when apparently healthy individuals are screened at community level compared to the more acute and visible infection *P. falciparum* (6, 256) which makes its proportion lower at community level; though other studies do not support this notion (257-260). On the other hand, proportional increment of P. vivax in the control site (Fig. 4) might be due to resistance development of the malaria parasite to chloroquine, which had been reported from the same site (261) and elsewhere (262, 263) in the country. However, as both species drastically decreased later, this the account due to resistance to Chloroquine needs further confirmation. Regarding the age distribution of

the *P. falciparum*, the current study reveals generally similar proportion in all age in both sites which is different from another study (260) which reported linear decline of the *P. falciparum* proportion as age increased.

The current study shows that the proportion of mixed infections *(SM)* is less than the findings of other studies (264-266) which reported proportion of 6.0% or above. However, another study reported somehow less proportion of *SM* than the present study (267). Yet, studies which employed molecular methods (268-272) revealed that the proportion of *SM* is more than what is usually reported as microscopic examination underestimates the actual proportion of the *SM* malaria and the overall prevalence of total infections as well. Similar to another study (273), there was no difference in distribution of the proportion of the MS among different age groups in this study. This condition has practical implications in light of the proper treatment of cases and effective control of the disease (274) where *P. falciparum* and *P. vivax* are endemic.

In this study, the use of secondary data might have underestimated the extent of the malaria burden in both sites. However, this condition would not introduce systematic bias in the analysis and comparison of trends of malaria prevalence, as both sites might have a similar chance of missing/capturing malaria records. Again, malaria treatment in government health care services is for free in Ethiopia, so that most of the malaria cases, if not all, are expected to be more attracted to local government health care services than to private health institutions, which are on payment basis. Therefore, this study is believed to have reflected the true picture of malaria burden and its trend in the study sites.

5.2. Dynamics of *P. falciparum* and *P. vivax* in a Micro-Ecological Setting, South-west Ethiopia: Effects of Altitude and Proximity to a Dam

Majority of *P. falciparum* malaria occurs nearer to the Dam, within two kilometer radius of GGHD and shows increment with distance from the Dam. The finding is in contrast to previous local studies (129, 148, 275), though those findings were not reported in terms of *Plasmodium species* composition. Moreover, the possible reason could be due to the underlying population density, which has been considered in the present study as an offset variable whereas in the other findings information on the underlying population density has been hardly articulated. The spatial variation in the occurrence of *P. falciparum* in a small geographical area was congruent with other findings (33, 54, 126, 276). However, the present finding is in contrast to previous local findings where the risk difference for *P. falciparum* between children who used to live within three kilometers of GGHD and beyond eight kilometers was insignificant (116, 132). Again, another study reported that distance to water bodies was not significantly associated with prevalence of *P. falciparum* malaria (115).

The underlying reason for the exhibited *P. falciparum* malaria increment with altitude above 1900 masl could be due to the up scrolling of malaria to highland areas possibly because of change in climate variables as had already been evidenced elsewhere (229, 277). The fact that *P. falciparum* occurs in the area mainly for short period of time following heavy rainfall from September to November usually in the form of epidemics (278) might have played a role in increasing the number of cases with the altitude as more susceptible individuals are exposed to the infection for relatively shorter duration due to the wave of epidemics.

On the other hand, the observed decline of *P. vivax* malaria episodes as altitude increased is similar to another finding (246) . The proportional increment of *P. vivax* malaria episodes with distance from the Dam is in agreement with a previous local finding which indicated that, unlike *P. falciparum* malaria, more *P. vivax* malaria among distant community compared to those close to a large dam (56); however, the underlying rationale is not clear and needs further explorations as the *P. vivax* has been given less attention and under studied (279) in spite of the fact that it poses potential severe health impact (135, 280-282).

As to the trend of the disease, the significant rise of *P. falciparum* malaria from 2006/7 to 2009/10 in reference to 2003/4 could possibly be due to resistance development by malaria vector mosquitoes to insecticides that had been in use for indoor residual spraying (IRS) in the country for about half of a century until vector resistance to DDT was detected in 2007 (87, 206, 207). On the other hand, the decline of *P. falciparum* malaria episodes in 2004/5 and 2005/6 might also be attributed to the scale up of interventions, including LLINS (80, 283), following the large scale malaria epidemics of 2003 (284, 285), implying the need for monitoring of major malaria intervention tools such as IRS & LLINS.

The apparent decline of *P. falciparum* malaria episodes after 2010 might have been due to the replacement of old LLINS in 2009, and shifting of insecticide used for IRS in 2010 to deltamethrin or bendiocarb insecticides (87), such coincidence of interventions followed by a sharp drop of malaria episodes as had also been reported by many other findings (47, 161, 208-210, 286) whereas weakened interventions and development of resistances of the vector to insecticides and the parasite to drugs have been documented to be associated with the resurgence of the diseases (287).

On the other hand, the sharp drop of malaria after major epidemic might be due to resistance to the disease induced by the epidemic itself as large proportion of the population are exposed to infection simultaneously which can induce herd immunity at least for short period of time. This needs further exploration to get insight into the resistance level of a community because of exposure to large scale of malaria epidemic.

5.3. Correlation of Climate Variability and Malaria: a Retrospective Comparative Study, Southwest Ethiopia

This study examined also the correlation between three major climatic variables, which are known to affect the dynamics of malaria (rainfall, relative humidity and temperature) (9, 60, 139, 186), and both monthly number of all types of confirmed malaria episodes as well as *P. falciparum* malaria. Although the GGHD site is situated at slightly lower altitude range, both sites are found within malaria risk altitude ranges (132, 254), the number of malaria cases was higher in the control site possibly due to plenty of rainfall over the period considered compared to the GGHD site. The correlation of persistent malaria transmission with such continuous higher level of rainfall is in agreement with prediction model of malaria transmission in Africa (31, 288). However, it is inconsistence with finding of a local study that reported risk of malaria was found to be higher at lower altitude (289).

The overall observed positive correlations between number of malaria episodes and rainfall in the current study, is similar with the estimated epidemic prediction of 2 to 4 months after rainfall in East Africa (290). However, when separately analyzed by study sites, both rainfall and relative humidity were positively correlated with prevalence of malaria in the GGHD, whereas negative correlation was observed in the control site up to three-month lag for rainfall, two-months lag for relative humidity. Such negative correlation of temperature and occurrence of malaria cases was reported by another study as well (291).

The site specific correlation of malaria prevalence and climate variables at different time lags in different eco-epidemiological settings were also indicated by other studies (17, 197, 292, 293). On the other hand, the absence or weak correlation of the climate variables with malaria occurrence were highlighted by certain studies (294, 295) whereas still other studies underline the strong correlation of climate variables with number of malaria cases (190, 296-300). The modest correlation of rainfall and relative humidity with prevalence of malaria observed in the GGHD site is congruent to another local study (148), which reported lags of two to three months as well. Other studies reported correlations of shorter lags (147, 178); however, another local study indicated more time lags (197).

Furthermore, other studies (9, 25, 145) underscored that the dynamics of malaria is determined by multiple contributing factors, the correlation between malaria and climatic variables is not always direct one and reliance on only climatic variables for prediction of malaria occurrence may not be sufficient. The correlation between climate variables and malaria occurrence simply indicates the presence of a linear relationship between them; but the absence of correlation doesn't prove the absence of association of climate variables with occurrence malaria. In a setting where minimal variability of temperature prevails and existing conditions are favorable for malaria, it may be difficult to distinguish the role of fluctuation of climatic parameters on malaria prevalence (301). Moreover, eco-epidemiological variability and species of malaria vector difference in different settings impose additional uncertainty on the generalizability of findings to other settings. Therefore, consideration of local specific factors is important in the battle against malaria.

5.4. Predictors of Long-Lasting Insecticide Treated Bed Nets Ownership and Utilization

This study tried to assess possession and utilization of LLINS of households of rural communities. Attempts have been made also to identify associated factors that influence ownership and utilization level of households comparing the study sites on the basis of characteristics that can possibly make the difference. The overall coverage of LLITs among the study HHs is similar to report of previous local studies (302, 303). However, it is below the findings other local studies (304, 305) and the coverage recommended by the World Health Organization (176, 306) to get an acceptable level of protection. The ownership level in the GGHD site was relatively higher while that of the control sites was less than the average figure indicated in the World Malaria Report of 2011 (median = 56%) (306) from household surveys results.

Regarding the utilization of LLINS among the owing households, the control households reported slightly higher percentage, which is almost the same with the report of study in Southern Ethiopian (307). The mean number of LLINS owned by households and their utilization rate is similar with the report of a previous study that covered three big regions of Ethiopia (308). The utilization of LLINS among households who had at least one was also similar to other local findings (80, 309) and it is within the range of findings from different African countries (162, 310-313),which were also below the WHO recommendation of 80% utilization. However, the utilization level identified by the current study is higher than a previous local study finding (314), which was still by far lower.

In this study, the suggested average cost of LLINS (17.0 Birr ≈ $ 0.9) is similar to one previous finding where nearly half of the study participants suggested 10 Birr for an ITN (315). This is far below what others reported both from local (316, 317) and some African countries (99, 318, 319). The facts that control households were more ready to buy and reported more utilization was higher than GGHD households implying that the control households were more aware of the benefits of LLINS, possible due to awareness created by the adverse effects of malaria (193, 320, 321), since it was more prevalent in the site.

The positive correlation between HH wealth status and possession of LLINS observed in the current study is similar to other findings where the household wealth status positively associated with ownership of LLINS (322-324) as possibly the wealthiest could be accessible to information to seek and receive or buy LLINS. The correlation between wealth index and number of LLINS owned observed in the present study is in agreement with other studies (325-329) that inequalities were observed in the number of ITNs owned and average number of ITNs possessed in which case the poorest were disadvantaged.

But, it is different from findings of other studies (109, 330, 331), which failed to show difference among socioeconomic strata with respect to possession, especially when LLINS distributed for free. Still, other studies reported that neither SES, cost nor educational level of mothers was associated with possession and utilization of LLINS (332, 333). Moreover, a study conducted in Gabon reported an inverse relationship between SES and bed net utilization (334). As indicated by another study (335), such inconsistencies might be due partially to the underlying measures of HHs wealth indices.

Unlike other findings (327, 328), factors such as gender, educational, occupational, marital status of household heads and family size did not show significant difference both in possession and utilization of LLINS in the present study. This is in line with a study that reported no difference between educated and non-educated mother to use ITNs (332). However, other studies (336-338) reported that the aforementioned factors significantly associated with the possession and utilization of LLINS among under five years children. Again, an another study (339) reported that financial inadequacies at the household level and poor perceptions of caregivers adversely affect utilization of LLINS among the under five years children. The current study is comparable with other studies (62, 326, 327, 340) with respect to the importance of distance to nearest health services or markets (possibly due to transportation accessibility), LLINS distribution points, and residences to account for the inequalities in possession and utilization of LLINS. The absence of significant association between utilization of LLINS and occupational status of the heads of the HHs in current study is different from the findings of a local study (341) and another study in Nigeria (328), which reported significant correlations of occupational status and educational level of HH heads with the utilization of the LLINS.

5.5. Prevalence of malaria in the Community where District-based Model and Community-based Model Indoor Residual Sprays Applied

Indoor residual sprays (IRS) and long-lasting insecticide-treated bed nets (LLINS) are the major malaria protective measures in Africa (158, 170). In Ethiopia, DDT had been the insecticide of choice for IRS for about half of a century. In some areas where the *An. arabiensis* had developed resistance to DDT, Malathion was applied as an alternative insecticide. However, high resistance of malaria vectors to these insecticides was detected in 2007 (87) and replaced by pyrethroids (deltamethrin) and bendiocarb. Additionally, the Government of Ethiopia has scaled up the distribution of LLINS to areas where the transmission season exceeds three months (88, 342). Consequently, the number of malaria cases has been significantly decreased over the past few years (174).

The present study was conducted in a high malaria transmission area, where both IRS and LLINS are in use. The observed very low malaria prevalence might have been attributed to the combined effect of IRS and LLINS, as there have been evidences that combined effect of IRS and LLINS in reducing malaria morbidity is higher than the use of either alone (343, 344), even though the average number of LLINS used by the study population was far below the recommended coverage level by the World Health Organization (345) for such large family size community to account for the observed sharp decrease in malaria prevalence. So, the identified low malaria prevalence in the present study is likely attributed to the implementation of IRS two months just before this study. Besides to the modalities of IRS implementation, the difference between the study sites might be due the fact that residents of Kersa, where the community-based model piloted, were better off regarding household relative wealth index and average number of LLINS owned by households as compared to villages where district-based IRS was applied.

The positivity rate of malaria was similar across age groups although the prevalence seems higher among children less than five years of age. This is congruent with a previous study (346) that all age groups were similarly affected. But, it is different from the findings of other studies (227, 347, 348), which reported higher malaria prevalence among the children. The low positivity rate (1.2%) was similar with a community level local study (349), but lower than facility based studies. The preva-

lence of malaria was still far below the prevalence of malaria reported by an earlier local study (194) in under five years of age children.

The fact that the positive cases identified only in GGHD site and the number of positive cases was very small, assessment of the true difference of the malaria prevalence and the factors affecting the prevalence in the two sites employing appropriate statistical analyses was not possible. Yet, the finding is programmatically meaningful to policy-makers and health managers when considered in the light of the envisaged plan of minimizing malaria cases in malarious areas of the country by 2015 and eliminating it by 2020 (350). Regarding the proportion of Plasmodium species, the present finding is similar to Ethiopia malaria survey of 2007 (80), where the proportion of *P. falciparum* and *P. vivax* were 70% 30% respectively; although the compositions wary slightly across age strata. However, the present finding is conversely related to previous local study (132) on children of less than ten years of age.

With respect to spatial distribution, the prevalence of malaria no difference was seen in villages close to the Dam and those beyond three kilometers from the Dam. This finding is similar to one longitudinal study (116) from the same area that proximity to the Dam did not show a significant association with malaria incidence; however, other previous studies (56, 132) reported that the risk of malaria incidences increased near the hydroelectric dams compared to villages three or more kilometers away from the banks of the dams. Such discrepancy might be due to change in malaria epidemiology, which could in turn be attributed to malaria vector breeding habitat. Methodological and temporal differences can also account for the inconsistency of findings, where the present study is a cross-sectional study in design and conducted in an era when preventive and control interventions have been scaled up. Therefore, it is not possible to conclude at this stage whether the Community-based IRS model works as the Districted-based IRS model or better.

6. Validity and Generalizability

6.1. Internal Validity

This study employed sufficient sample size for the household and blood surveys so that the role of chance has been controlled, thus the observed results are believed to be true. Appropriate analytical methods and study designs were also applied to control possible confounders. Questionnaire was translated to local language for clarity and ease of understanding of concepts; and back translated to English language to keep its consistency.

Data collectors and supervisors were well trained on the concepts and objectives of the study as well as technique of interviewing respondents. Blood sample collection was done by health extension workers who had training and experience on the collection and testing of blood samples using RDTs. During the data collection and conducting tests, they were supervised by experienced senior laboratory technologists. Additionally, all the positive tests and 10% of the negative tests were re-examined using microscopy by the laboratory technologists and all the re-examined tests were consistent with RDT tests. Therefore, the findings of this study are believed to be internally valid and the findings can be surmised as an actual reflection of malaria situation in the study area.

6.2. External Generalizability

Since the study conducted in a setting, where hydroelectric dam constructed about a decade back that inevitably creates micro-ecological changes, the current findings can supplement those limited previous findings from the same/similar settings to prompt policy-makers the distribution of malaria both in the vicinity of the dam and another similar locality. With respect to the current expansion of hydroelectric dam construction in Ethiopia, the present study is believed to contribute valuable information, not only about the present, but also it lays a baseline to support future studies in similar settings to shade light on the possible adverse health outcomes as the consequence of anthropogenic imposed environmental modification. However, by nature malaria is usually complex and dependent up on multifaceted factors, external generalizability depends on the similarity of the prevailing conditions where and when generalization is required to be made.

7. Strengths and Limitations

7.1.Strengths

While assessing wide aspects of the disease, the study has made use of a large set of data accumulated over long period of time to grasp temporal patterns, spatial distributions with respect to artificial lake and altitudinal malaria distribution by species compositions.

The study has triangulated also different data sources, including fairly long period data of health services based malaria episodes records, community based blood survey to evaluate prevalence of malaria in the community and household survey to assess the status of current major malaria interventions. Again, triangulation of methods were made to enhance holistic understanding of the factors that influence malaria dynamics in the areas. Main climatic variables known to affect the transmission of malaria were incorporated into the analysis of malaria trends to identify the role of the climatic variables on malaria in the areas. In this study, major malaria interventions, including LLINS and IRS status as well as factors affecting accessibility to the interventions were also assessed to get contextual information.

7.2. Limitations

The use of secondary data might have underestimated the extent of the malaria burden in both sites due to factors related malaria diagnosis limitations of the local health facilities (351) and many symptomless (255, 352, 353) members of the community even do not visit health facilities at all. Lack of uniformity in diagnosis of malaria (clinical, RDTs & microscopy) might had compromised the true picture of the disease in the study sites, as cases were treated clinically at previous clinics before the era of RDTs. However, this condition will not introduce systematic bias in the comparison of trends of malaria prevalence as both sites have a similar chance of missing/capturing malaria records. Again, malaria treatment in government health care services is free in Ethiopia. So, most of the malaria cases, if not all, are expected to be attracted more likely to local government health care services, at least for the first visit than private health facilities, which is based on payment.

The number of available variables in the secondary data were limited. In spite of dealing with large data set, the absence of required variables in the secondary data, such as socioeconomic and demographic factors, precluded more detail analysis of malaria predictors at household and community levels. Another possible limitation of this study is the use of climate variables from adjacent stations in the absence of the data directly from the study sites. In this regard, temperature and humidity data for the control site was taken from Jimma station; and for the GGHD site, humidity data was used from Sokoru Station. Both Jimma and So koru Stations were close to the control and the GGHD study sites respectively; thus expected to have similar weather conditions as there is no magnified geographical difference in terms of altitude and coverage of vegetation between those stations and the respective study sites.

In addition, imputation method was used to fill the missed humidity data of three years using the average of the respective months. This may affect the findings to a certain extent. Social desirability bias might affect the response of LLINs utilization level, which underestimates the true utilization; however, it doesn't affect the comparability of the study populations. Some of the figures, such as accessibility to facilities, income information were based on the respondents' perceptions. Although this condition is expected to affect the results to some extent, it has been similarly implemented for both study sites. So, comparability of the findings are not expected to be affected.

The fact that the positivity rate of the blood survey was very low and limited only to GGHD site, limited analysis to be descriptive. Due to the very low number of positive cases, regression analysis was not possible to rule out true difference controlling for competing factors. Therefore, as this is a one-time study and the positivity rate was very low, it is not possible to conclude whether the Community base IRS model works as the District base IRS model or better to control malaria.

8. Conclusions

- All age groups of the study population were affected by malaria similarly and slightly more males than females experienced the disease. Malaria occurrence appeared to follow different patterns in the study sites. More malaria was observed in the control site compared to GGHD site. The present finding did not show evidence of excess malaria burden in the GGHD site due to the presence of the Gilgel-Gibe Hydroelectric Dam; however, irrespective of the lower prevalence in GGHD site, the trend of malaria prevalence of the GGHD site was more steeply increased than that of the control site, which warrants close monitoring.

- The recent fall of malaria cases coincided with malaria intervention, particularly the shift of insecticides used for indoor residual spray from DDT/Malathion to deltamethrin/ bendiocarb.

- The *P. vivax* main peak transmission was during February to April and that of P. falciparum was the reverse of *P. vivax* peaks. The proportion of *P. falciparum* malaria was higher in GGHD site compared to the control site; whereas the proportion of *P. vivax* which prevailed almost round the year and was higher in the control site.

- , the distributions of *P. falciparum* and *P. vivax* were similar in spite of the fact that *P. falciparum* was more prevalent. Spatial distribution of the two species was different and that the majority of the *P. falciparum* episodes were registered to occur close to the GGHD. However, unlike *P. falciparum*, the *P. vivax* episodes were not limited to the proximity of the Dam. Rather, *P. vivax* episodes were limited mainly to relatively lower altitude ranges.

- Correlations of malaria and clim*ate variables* were *differe*nt for the two sites; in GGHD site, rainfall and relative humidity are the driving forces behind malaria at 2 to 3 months lags. On the other hand, weak/absence of correlation in the control site does not prove absence of association between malaria and climate variables; it simply implies absence of linear relationship between them.

- Disparities have been seen among households in both ownership and utilization of LLITs. The poorest, distant from health facilities, inaccessible to vehicle transportation households were found to be the most disadvantaged in possession of LLINS. Factors that adversely influenced utilization of LLINS were household RWI, distance to health facilities, inaccessibility to vehicle transportation, being in the control area, larger family size, households with heads that were not in marriage, and households with older heads.

- Malaria case was not identified from villages where community-based model of the IRS was implemented. The identified cases of malaria from villages where a district - based model of the IRS implemented needs careful future monitoring to examine whether it was due to quality compromised IRS applied in the district - based model or other factors, such as presence of GGHD or due to socioeconomic differences.

9. Recommendations

9.1. Health service management

- Due attention needs to be given to the poor, distant and inaccessible households in the effort of malaria intervention programs such as during free distribution of LLITs.
- Well-tailored information education and communication (IEC) is needed to address the problem of non-users, especially, households with older heads deserve appropriate IEC.
- The continuity of effectiveness of malaria interventions in controlling malaria, especially in hot spot areas, needs vigilant monitoring.
- As already family folders are thought to exist at health post level, patient records at health facility level should include family identity (ID) so that spatial analysis of diseases and inclusion of more variables (for detail analysis) can be carried out efficiently by linking case history to the family ID when needed.

9.2. Community level:

- Due attention need to be given to children in the age range from 10 to 14 years together with the other vulnerable group of the population.

9.3. For future research:

- There is a need to consider additional factors such as NDVI and the physico-chemical nature of the water bodies to assess malaria risk factors of a locality that play a role in the rate limiting of the dynamics of malaria.
- Regarding the limit of *P. falciparum* with altitude and that of *P. vivax* with distance from dams, further exploration is needed involving larger scale study.
- Applicability and level of effectiveness of the community-based model of IRS need to be further explored in different localities to fully replace the district based model of IRS.
- Regardless of the inherent limitations of the secondary data, researchers need to consider the use of thick data accumulated in health facilities for years.

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12. Annexes

Annex- I Published and submitted articles

1. Paper one

Sena et al. Malaria Journal 2014, 13:188
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MALARIA JOURNAL

RESEARCH Open Access

Analysis of trend of malaria prevalence in south-west Ethiopia: a retrospective comparative study

Leliso D Sena[1,2*], Wakgari A Deressa[2] and Ahmed A Ali[2]

Abstract

Background: The temporal analysis of pertinent malaria data on the health care system is crucially important to measure success or failure of malaria programmes and identify remaining malaria hot spots. The objectives of this study were to analyse and compare trends of malaria prevalence around Gilgel-Gibe Hydroelectric Dam (GGHD), and a control site over an eight-year period.

Methods: A retrospective record review of health care services was conducted in southwest Ethiopia. Records of malaria cases over an eight-year period in primary health care units of two localities were reviewed. One study site was selected from villages around a man-made lake, GGHD, within a distance of 10 km, and a control site with similar geographic features was identified. Data were summarized in tables; prevalence of malaria was analysed and described by person, place and time using line graphs. Odds ratio was used to examine significant difference of malaria occurrence in the two sites.

Results: Records of 163,918 malaria cases registered over eight years (September 2003 to August 2011) were explored. Close to one thirds (32.7%) of these cases were from GGHD site and two-thirds (67.3%) of them were from the control site. Among the confirmed cases, *Plasmodium falciparum* constituted 54.6%, *Plasmodium vivax* accounted for 41.6%, and mixed infection was 3.8%. There were three peaks of malaria prevalence in the control site whereas only one major peak was identified during the eight-year period in GGHD site; and prevalence of malaria in GGHD site was lower than control site. Children in the age range ten to 14 years were the most affected by the disease, followed by children below the age group five to nine years, which demands due consideration in the effort of malaria control.

Conclusions: More malaria prevalence was observed in the control site compared to GGHD site almost throughout the time period considered. The present finding did not show evidence of the excess malaria burden in the GGHD site due to the presence of the dam.

Keywords: Ethiopia, Gilgel-Gibe, Health service, Malaria trend, Malaria prevalence

Background

Malaria has been a major public health problem throughout human history, particularly in the tropical and subtropical parts of the world [1]. In Ethiopia, the occurrences of epidemics of malaria have been documented since the 1930s and 1940s. The most devastating epidemic was that of 1958 which resulted in an estimated three million cases and 150,000 deaths [2,3]. Until recently, malaria has been the leading cause of morbidity and mortality in Ethiopia [4-6]. The two peak seasonal transmissions of malaria occur during the months of September to December and March to May [4,7].

Studies have shown that the *Plasmodium* species compositions and the number of malaria cases vary over time [8-11] due to different factors, such as previous weather conditions [12] or intervention measures [13]. A hospital based retrospective study done in Ethiopia revealed decrement of *Plasmodium vivax* whereas *Plasmodium*

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falciparum increased over a five year period [7]. Another ten year trend study carried out in Jimma Town, Ethiopia, showed not only fluctuation of number of malaria cases but also changes in the species of *Plasmodium* composition following climatic variables [14].

Understanding how malaria varies in the community as a result of seasonal or year to year changes is essential for planning national malaria control programmes [15]. The temporal analysis of relevant malaria data of health care system gives essential information needed to measure achievements of national malaria programmes and scrutinize remaining malaria hot spots. It also gives important insight into the changing malaria situation, which might guide adjustments of malaria programme activities and the prioritization of malaria research [16,17]. Therefore, the changing malaria situation requires an updating description of malaria trends [18].

Comprehensive studies regarding prevalence of malaria over a period of time that includes all age segments of the population, taking into account the base population (denominator), are scarce in Ethiopia in spite of the recognition of the disease burden for more than half of a century. Therefore, the objectives of this study were to analyse and compare trends of malaria prevalence around Gilgel Gibe hydroelectric dam (GGHD) and a control site and to identify trends of *Plasmodium* species over the time period considered.

Methods

Study settings

This record review comparative study was conducted in two rural settings; one site was surrounding a man made lake, GGHD, which started operating in 2004 [19], and a control site was more than ten km far away from the lake so that the possible effect of the dam would not be reflected in the control site. The GGHD site is a health and demographic surveillance site (HDSS) [20] which includes surrounding villages within ten km radius of the GGHD and about 50,000 residents used to live in the villages. The control site was selected considering the similarity of geographic features with the Dam site regarding altitude and presence of rivers, but without dam, and equivalent ranges of distance from water bodies as main risk of malaria. The population of the two sites had similar socio demographic characteristics and economic activities. Both sites are found within altitude range which favors seasonal malaria transmission [21-23]. A previous survey showed that the two sites had equivalent household sizes of about five individuals per household [21], thus, equivalent villages and small towns with that of the GGHD were identified from the control site with about 50,000 mid year population; thus, an estimated 100,000 mid year population contributed to the malaria cases from the two study sites.

The residents of both study sites had accessibility to primary health care units. A primary health care unit consists of a health centre and, on average, five health posts together serving about 25,000 population in a radius of about five km of the health centres. The health centres are usually staffed by middle level health professionals, including laboratory technicians and technologists, thus cases with fever are often tested for malaria. The health posts are staffed by health extension workers as of 2005 [25], and they could perform rapid diagnostic tests for malaria suspected cases and treat uncomplicated malaria cases. Detailed descriptions of the study settings have also been given elsewhere [21,22,24].

Study design

A retrospective comparative study design was employed using data from local health services (health centres and health posts). This was done by reviewing malaria morbidity records of local health facilities pertaining to villages within a specified radius of the GGHD and the control site. Trend of malaria prevalence was analysed and compared by person and place.

Source of data and sample size

In Ethiopia, malaria cases are treated both clinically and as confirmed malaria accordance to national guideline [6,26] depending on the degree of diagnostic capabilities at different levels of the healthcare system. Both the presumptive and confirmed cases are registered on preformatted registration books (log books) at health care levels and reported both weekly as well as monthly to next higher level of health management system. The present study included all malaria records of the local primary healthcare units that were within the environs of GGHD (Gilgel Gibe DHSS) and control villages registered by the primary health care units between September 2003 and August 2011 were reviewed. In the GGHD site there were eight health posts and three health centres from where records of malaria cases visited the health services only from villages included into the Gilgel Gibe DHSS were considered for the present study. Similarly, villages in the control site had eight health post and one health centre from where only malaria records of the selected villages included into this study. The timeline consideration was based on data availability both for GGHD as well as control sites, and the fact that significant change in the number of malaria cases, such as epidemics, occurs in cyclic fashion from five to eight year periods in the country [4,27,28], in order that any fluctuation of such cycle could be captured.

Data collection techniques

A format was prepared on a computer spreadsheet (Excel) to collect the secondary data from log books of

local government primary health care units of the area. Individual level data on malaria morbidity, such as, diagnosis results (negative, species of *Plasmodium* for positives), dates of diagnoses, available demographic data (residence, age, sex) were registered on the computer spreadsheet. All records of patients who visited the health institutions during the timeframe considered and treated as malaria patients were included in the study. Records of cases with incomplete records, such as dates of health service visit, age, address, results of diagnosis, were excluded from the analysis.

Data management and processing

The data on malaria case records of different local healthcare institutions of the study sites were transfered to Excel spreadsheet, checked for completeness (date of diagnosis, test results, patient age and address), coded and combined on the same spreadsheet; then, prepared data of malaria cases were exported to SPSS statistical software version 20 for Windows. Subsequent analyses were performed using the SPSS statistical software. Results were summarized using tables and figures and odds ratios were used to estimate the level of difference between the study sites in the distribution of malaria prevalence.

Ethical considerations

Ethical clearances were obtained from the Addis Ababa University College of Health Sciences Ethical Review Board and Oromia Regional Health Bureau Ethical Clearance Committee. Jimma Zonal and District Health offices as well as local administrators were communicated by formal letters written from School of Public Health of Addis Ababa University and Oromia Regional Health Bureau. Individual information was kept confidential and the names of individuals were removed from data of health services and identified only by identification numbers and the results were communicated in an aggregated manner.

Results

This retrospective study examined records of 163,918 malaria cases registered over eight years (September 2003 to August 2011). Close to a third (32.7%) of those cases were from the GGHD site and two thirds (67.3%) were from the control site. Overall, the male to female ratio was 1.09: 1 and slightly higher for the GGHD site (1.12:1 vs 1.06: 1) than the control site. The under five age group constituted 12.0% of all the cases, which was higher in the control site (12.7% vs 10.9%) than GGHD site. The proportion of children aged from five to fourteen years was 28.0% (28.3% in control vs 27.6% in GGHD); the proportion in the age group ten to fourteen years was higher among the control (16.3% vs 14.4%) than the GGHD site. On the other hand, the composition of adult cases aged 15 years and above was higher in the GGHD site (62.3% vs 59.0%) than the control site. Regarding the composition of age group between males and females within the study sites, there was similarity in the GGHD site whereas in the control site more girls in the age range ten to fourteen years were affected (17.2 vs 15.3%) than counterpart boys; however, in the adult age category more males than females (60.7 vs 57.1%) were infected (Table 1).

About two thirds were confirmed uncomplicated malaria cases and a third were clinical malaria cases, including probable malaria cases. Overall, *P. falciparum* and *P. vivax* accounted for one third and one quarter of all the cases, respectively, with similar proportion across all age groups. Pertaining to the species composition among the confirmed cases, *P. falciparum* constituted 64.6% (60.4% in GGHD site and 62.3% in the control site), *P. vivax* accounted for 31.6% (33.6% in GGHD and 44.7% in control) and mixed species was 3.8% (6.0% in GGHD and 3.0% in control) of the confirmed cases.

There have been higher proportion of infections in control site by both *P. falciparum and P. vivax* species in all age categories. Infection by *P. falciparum* and *P. vivax* malaria was 1.5 and 2.2 times more likely to occur in the control site compared to GGHD site among the under five years of age group. The prevalences of *P. falciparum* and *P. vivax* was respectively more than two and three times likely to occur among children five to fourteen years age group in the control sites compared to the GGHD site. Among the adults fifteen years and above years of age, the prevalences of *P. falciparum* and *P. vivax* were 1.7 ans 2.7 repectively more likely to happen in the control sites compared to the GGHD site (Table 2).

There was variation of trend of confirmed malaria among different age groups as well as year to year trends. Children in the age range from ten to fourteen years were the most affected by the disease. As depicted in Figure 1 (red line), the prevalence of malaria was highest in this age category from 2003 to 2010 when the prevalence of malaria dropped in all age groups. Especially, in 2006, a child in this group got more than two infections and, on average, a child got nearly three infections in 2008. Children below the age of ten years were the second most affected following those aged ten to fourteen years. In 2006, children below ten years got on average 1.5 infections and from 2008 to 2010, they got more than two infections of *Plasmodium* yearly. However, there was not much pronounced visli difference between children in the age group below five years (pink line) and those five to nine years (cyan line) age categories, although the latter was slightly higher.

Table 1 Distribution of malaria cases by sex, age and study sites, southwest Ethiopia, September 2003-August 2011

Sex	Age group in years	Gilgel Gibe		Control		Total
		N (%)	Row %	N (%)	Row %	N (%)
Male	≤5	2,954 (10.4)	28.5	7,220 (12.7)	71.5	10,174 (12.0)
	5-9	3,540 (12.5)	38.8	6,353 (11.2)	61.2	9,893 (11.6)
	10-14	4,015 (14.2)	36.3	8,712 (15.3)	63.7	12,727 (15.0)
	15+	17,829 (62.9)	33.3	34,480 (60.7)	66.7	52,309 (61.5)
	Subtotal	28,338 (100.0)	33.3	56,765 (100.0)	66.7	85,103 (100.0)
Female	≤5	2,859 (10.5)	29.9	6,801 (12.7)	71.1	9,660 (12.0)
	5-9	3,320 (13.1)	35.2	6,871 (12.8)	64.8	10,191 (12.9)
	10-14	3,733 (14.8)	32.6	9,273 (17.3)	67.4	13,006 (16.5)
	15+	15,374 (61.8)	32.3	30,584 (57.1)	67.7	46,158 (58.6)
	Subtotal	25,286 (100.0)	32.1	53,529 (100.0)	67.9	78,815 (100.0)
Total	≤5	5,813 (10.5)	28.7	14,021 (12.7)	71.3	19,834 (12.4)
	5-9	6,860 (12.4)	37.0	13,224 (12.0)	63.0	20,084 (12.5)
	10-14	7,748 (14.0)	34.4	17,985 (16.3)	65.6	25,733 (15.7)
	15+	33,203 (62.3)	32.8	65,064 (59.0)	67.2	98,467 (60.1)
	Total	53,624 (100.0)	32.7	110,294 (100.0)	67.3	163,918 (100.0)

Table 2 Distribution of confirmed malaria cases by age group and study sites, southwest Ethiopia, September 2003-August 2011

Age group (year)	Diagnosis	GGHD N (%)	Control N (%)	Odds ratio (C.I.)
≤5	*P. falciparum*	1437 (23.8)	4606 (76.2)	0.65 (0.53,0.80)*
	P. vivax	901 (18.2)	4056 (81.8)	0.46 (0.38,0.57)*
	P. mixed	145 (32.4)	302 (67.6)	1
	Sub total	2483 (21.7)	8964 (78.3)	
5-9	*P. falciparum*	2293 (33.6)	4530 (66.4)	0.47 (0.39,0.58)*
	P. vivax	1259 (23.9)	3994(76.1)	0.29 (0.24,0.35)*
	P. mixed	261 (52.1)	240(47.9)	1
	Sub total	3793(30.3)	8724 (69.7)	
10-14	*P. falciparum*	2260 (27.2)	6053 (72.8)	0.45 (0.38,0.54)*
	P. vivax	1323 (20.5)	5143 (79.5)	0.31 (0.26,0.37)*
	P. mixed	263 (45.1)	320 (54.9)	1
	Sub total	3846 (25.0)	11516 (75.0)	
15+	*P. falciparum*	10429 (33.2)	22045 (66.8)	0.61 (0.57,0.67)*
	P. vivax	5947 (24.2)	18676 (75.8)	0.40 (0.36, 0.45)*
	P. mixed	1011 (44.5)	1262 (55.5)	1
	Sub total	17387 (29.9)	41983 (70.1)	
Total	*P. falciparum*	16929 (31.3)	37234 (68.7)	0.58 (0.54,0.61)*
	P. vivax	9410 (22.8)	31869 (77.2)	0.37(0.35,0.40)*
	P. mixed	1680 (44.2)	2124 (55.8)	1
	Total	28019 (28.2)	71187 (71.8)	

*Significant at P < 0.0001.

On the other hand, the adult age group (blue line) was the least affected. In this age category, the prevalence of malaria reached 60% in 2005 and decreased by half the following year. However, the prevalence gradually increased and reached about 75% in 2008 where it levelled for the subsequent two years. The green line in the figure shows the overall prevalence of confirmed malaria in all age groups, which is seemingly lowest of all obscuring the burden of the disease in different age categories particularly in the children categories (Figure 1).

There was also a difference in the pattern of malaria prevalence between the study sites. Generally there were three peaks of malaria prevalence during the eight year period considered in the control site. The three significant malaria prevalence peak periods were in 2005, 2008 and 2010. In 2005, the prevalence of malaria reached 25% and the other two peaks were above this figure. The proportion of *P. falciparum* (brown line) and *P. vivax* (blue line) was almost equivalent throughout the period considered irrespective of the overall variation over time. The *P. falciparum* prevalence was slightly higher than that of *P. vivax* except in 2008 and 2010 when the *P. vivax* prevalence was elevated a little above *P. falciparum*.

On the other hand, prevalence of malaria in GGHD (orange line) was much lower than in control site (red line) and exhibited only one major peak during the eight year period. In the GGHD site, malaria prevalence was low and showed a slight decline before 2006, and the composition of *P. falciparum* (pink line) was only slightly higher than *P. vivax* (green line) species. Since 2006 however, the prevalence of malaria steadily increased in the site. The *P. falciparum* infection was

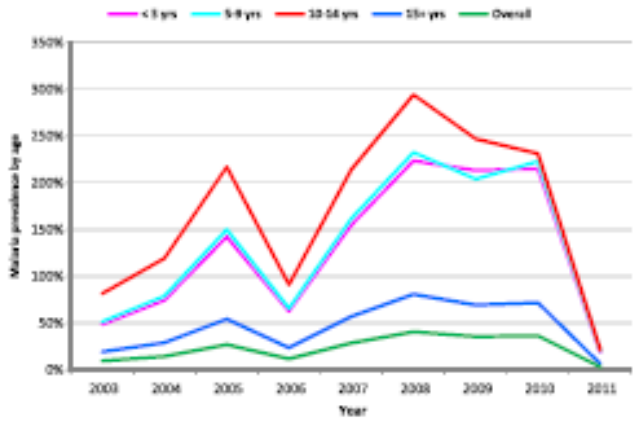

Figure 1 Trend of confirmed malaria prevalence by age group and year, southwest Ethiopia, September 2003 - August, 2011.

increased excessively and reached its peak in 2009 and declined the following two years. The increment of *P. vivax* prevalence was more gradual and it reached its highest level in 2008 and showed a very gradual decline since then (Figure 2).

Malaria prevalence was decreased both in GGHD and control sites from September 2003 to August 2004, then the patterns of malaria prevalence in the sites gradually followed different patterns. In the control site, the prevalence of malaria had been excessively higher since September 2004. From September 2004 onwards, the malaria prevalence was remained at higher levels throughout the year and dropped sharply in September 2005 and further reduced in December 2005. From March to September 2006 there was a peak during the six months. From September 2007 to July 2008, the highest rise of malaria prevalence was noticed in the control site. There were still peaks of malaria prevalence evident in the area during September to December 2008 and September 2009 to September 2010 for about two subsequent years until it dropped drastically almost to zero level in September 2011.

In the GGHD area, malaria prevalence was low starting from December 2003 to September 2006 with two small rises during the season of September to November 2004 and 2005. However, there was persistent and gradual increment of malaria prevalence during the subsequent four years with peak transmission of different magnitude during the months of September 2007, 2008 and 2009. The peak in 2008 coincided with that of the control area peak and the rise of prevalence in September 2009 was the highest one in the GGHD area. Since March 2010, malaria prevalence has decreased steadily in the GGHD area as well (Figure 3).

The average monthly distribution of malaria prevalence exhibited different patterns between the study

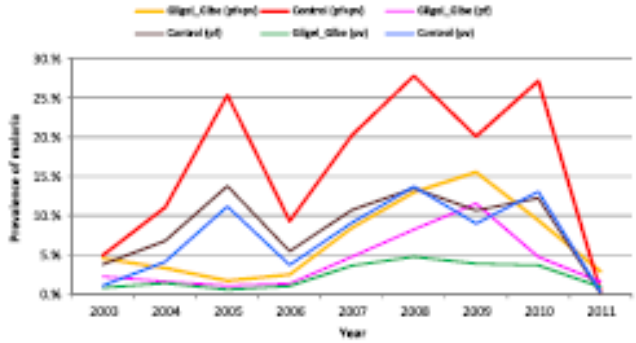

Figure 2 Trend of confirmed malaria prevalence by study sites, species composition and year, southwest Ethiopia, September 2003 - August 2011.

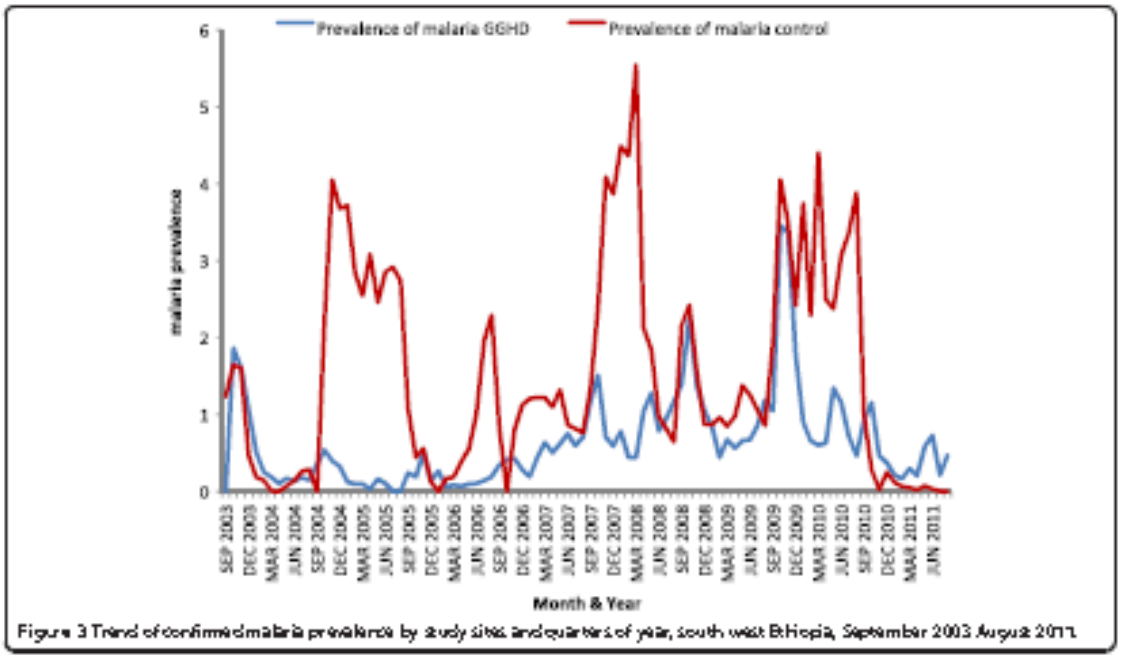

Figure 3 Trend of confirmed malaria prevalence by study sites and quarters of year, south west Ethiopia, September 2003-August 2011.

sites. Generally, two major peaks were noticed in the control site (red line). One peak was during the start of rainfall February to May and the other one was after the heavy rainfall from September up to December. The contribution of *P. falciparum* (cyan line) and *P. vivax* (navy line) was almost the same during the first wave but the *P. falciparum* contribution was found to be higher during the September to November peak transmission in general. In contrast, the prevalence of malaria in GGHD site (pink line) showed one major peak which was from September to November and of relatively shorter duration. The increment of malaria prevalence in GGHD site was entirely due to *P. falciparum* (brown line) infection which occurs usually in the form of epidemics. The contribution of *P. vivax* (green line) was very low and almost constant throughout the years (Figure 4).

Discussion

The essence of this study was to estimate and compare the prevalence of malaria, identify possible shift of *Plasmodium* species compositions over time in the two localities from the available data of the health services. The study considered only key individual characteristics (age and sex), date of diagnosis, diagnosis outcome and address of the cases in an attempt to minimize the usual limitations of secondary data such as incompleteness of information. In the country, mostly malaria cases are diagnosed and treated at primary health care level. Health extention workers who had been trained and deployed at village level since 2006 [25] can conduct also rapid diagnostic tests for malaria and treat uncomplicated cases at health posts level which are part of the primary health care unit. Such expansion of health services at grass root level has increased accessibility to health services and hence, there has been reports of positive health outcomes [29,30]. Yet, the two study sites have been exposed to similar improvement in health delivery system and such changes would not compromise the comparability of distribution of malaria in the two sites. Moreover, as the study dealt with a relatively large set of data, the appearance of findings due to chance is expected to be minimized. Thus, this retrospective healthcare service based study is believed to have assessed the distribution of malaria over a period of eight years by person, place, time, and composition of *Plasmodium* species.

The prevalence of malaria was excessively higher in the control site and characterized by several peaks of transmission through the timeline considered. Irrespective of the scale up of long lasting, insecticide treated bed nets (LLINs) since 2005 [5], the number of cases steadily increased from 2006 to 2008 when it reached the highest level in both study sites. Especially, *P. falciparum* malaria showed a drastic rise in the GGHD site during that period, possibly due to resistance development by malaria vector mosquitoes to DDT (75% WP) and partly Malathion (50% WP) that was in use for indoor residual spraying (IRS) in the country since 1960s until malaria vector resistance to DDT was detected in

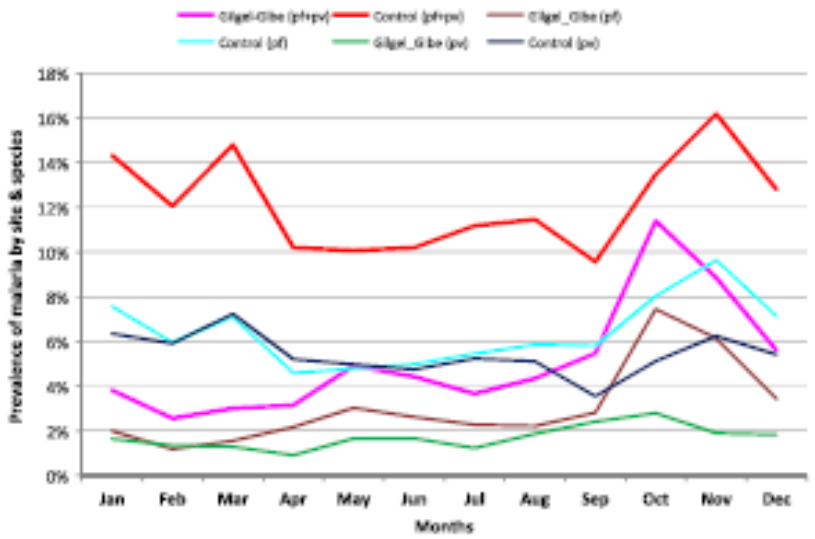

Figure 4 Trend of confirmed malaria prevalence by study sites, species and month, southwest Ethiopia, September 2003 - August 2011.

2007 [31-33]. The increment of malaria cases in GGHD site was still by far below that of the control site despite of the earlier report of a study [22], which was conducted a year after the construction of the dam in 2004, that indicated higher risk of malaria infection among children who lived within three kilometer radius of the GGHD as compared to those who lived eight to ten kilometer away from the dam. Again, a more recent report of longitudinal study of the same area showed that there was no significant malaria risk difference between children who lived in villages near to the dam and those who lived away from it and malaria was reported to be highly seasonal driven in the area [23]. This implies that access malaria risk due to the dam construction was not clearly evident over the long period of time as far as interventions are in place like other malarious areas.

After 2009 in the GGHD and 2010 in the control sites, sharp decline of the number of malaria cases was noticed, possibly due to the replacement of old LLINs in 2009, followed by shifting of insecticide used for IRS in 2010 to deltamethrin or bendiocarb insecticides [31], such coincidence of interventions followed by a drastic drop of malaria was also revealed by other findings [17,34-37] in other African countries. This suggests the need for the effective combined intervention methods using IRS with potent insecticides and LLINs as evidenced by different studies [38-40], as well as the need to monitor insecticide resistance of mosquitoes.

The contribution of *P. falciparum* was higher (60.3% vs 53.9%) in GGHD site than control site. This proportion of *P. falciparum* in GGHD site was similar to health facility based studies in Ethiopia [14,21], but less than other local findings [5,11,12] and still by far lower than other local findings of community based surveys [39,13], however, the proportion of *P. falciparum* in the control area lower than the report of health facility based study findings in Ethiopia. The proportion of *P. vivax* malaria was above 40% except in 2003/4 and 2008/9 when it was 25.1% and 37.9%, respectively. Especially, the proportion of *P. vivax* was higher (46.1% vs 33.6%) in the control site which might have contributed to the higher level of malaria prevalence in the site as it occurred almost at the higher and stable level during the time period considered.

The present study shows that slightly more males were affected than females which are similar to other findings [11,41-47] and, all age groups were found to be susceptible to malaria. However, children were more affected than adults, especially those in the age range ten to fourteen years were disproportionally affected. Similarly, other studies have reported susceptibility difference that children were more affected [18,19] than older age groups, but other studies have reported more susceptibility in adult age groups [46,50]; the latter might be confounded by other factors.

Reporting by absolute number or proportion of cases can be misleading unless the denominator of each age category is considered. For instance, in this finding Table 1 shows that the proportion of adult cases is higher by many fold than that of children, however, consideration prevalence (Figure 1), which takes into account respective denominators, points out that the children were actually the most affected ones. The fact that children aged from ten to fourteen years were more

affected than those below ten years suggests not susceptibility difference but exposure difference, such as giving priority to small children in the use of LLINs. This implies that analysis of extent of malaria burden needs to take into consideration the base (denominator) population.

In this study, the use of secondary data might have underestimated the extent of the malaria burden in both sites. However, this condition would not introduce systematic bias in the analysis and comparison of trends of malaria prevalence, as both sites might have a similar chance of missing/capturing malaria records. Again, malaria treatment in government health care services is for free in Ethiopia, so that most of the malaria cases, if not all, are expected to be more attracted to local government health care services than to private health institutions, which are on payment basis. Therefore, this study is believed to have reflected the true picture of malaria burden and its trend in the study sites.

Conclusions

Malaria occurrence appeared to follow different patterns in the two study sites. Two seasonal peak transmissions were annually observed in the control site due to both *P. falciparum* and *P. vivax* infections. However, only one short seasonal transmission was noticed in the GGHD site due to *P. falciparum* while transmission of *P. vivax* infection was at low and constant level throughout the considered period. The short duration rise of *P. falciparum* malaria in GGHD implies that malaria was driven by seasonal influence but not due to effect of the dam which would otherwise indicated persistent transmission of longer duration of the disease.

All age groups of the population were affected by malaria; however, the fact that children in the age group five to fourteen years were more affected by the disease suggests not higher susceptibility level but higher exposure status due to less attention given to these older children than the under five years of age. Therefore, due attention needs to be given to this age category together with the 'vulnerable' segments of the population.

Abbreviations

GGHD: Gilgel gibe hydroelectric dam; LLINs: Long lasting insecticide treated bed nets; OR: Odds ratio; SPSS: Statistical package for social sciences; Vs: Versus; WHO: World Health Organization; WP: Wettable powder.

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

LDS participated in the study design, undertook the field study, analyzed data and wrote the manuscript. WD participated in the study design, revision of the manuscript and facilitation of administrative issues. AAA participated in the study design, revision of the manuscript and facilitation of administrative issues. All authors have read the manuscript and approved it to submit for publication.

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2. Paper two

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RESEARCH ARTICLE Open Access

Dynamics of *Plasmodium falciparium* and *Plasmodium vivax* in a micro-ecological setting, Southwest Ethiopia: effects of altitude and proximity to a dam

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Abstract

Background: Refining the spatial and temporal data on malaria transmissions at a defined ecological setting has practical implications for targeted malaria control and enhancing efficient allocation of resources. Spatial and temporal distribution of *P. falciparum* and *P. vivax* were explored around the Gilgel Gibe Hydroelectric Dam (GGHD) in southwest Ethiopia.

Methods: A review of confirmed malaria episodes recorded over eight years at primary health services was conducted. Using individual identifiers and village names malaria records were cross-linked to location and individual records of Gilgel Gibe Health and Demographic Surveillance System (HDSS) data, which had already been geo-referenced. The study setting was categorized in to buffer zones with distance interval of one kilometer. Similarly, altitude of the area was categorized considering 100 meters height intervals. Incidence rate ratios were estimated using Poisson model for the buffer zones and for the altitudinal levels by adjusting for the underlying population density as an offset variable. Yearly temporal variations of all confirmed malaria cases were also evaluated based on the Poisson model using STATA statistical software version 12.

Results: A considerable proportion (45.0%) of the *P. falciparum* episodes were registered within one kilometer radius of the GGHD. *P. falciparum* showed increment with distance from the GGHD up to five kilometers and with altitude above 1900 meters while *P. vivax* exhibited the increase with distance but, decrease with the altitude. Both species showed significantly higher infection among males than females (P <0.01). Temporally, malaria episodes manifested significant increments in the years between 2006/7 to 2009/10 while reduction of the malaria episodes was indicated during 2004/5, 2005/6 and 2010/11 compared to 2003/4 (P <0.01). On average, *P. vivax* was 52% less than *P. falciparum* over the time period considered. P. vivax was significantly higher in the years 2004/5 to 2007/8 and 2010/11 (P <0.001).

Conclusions: Spatial and temporal variations of malaria were observed. The spatial and temporal variations of malaria episodes were also different for the two main malaria species in the area.

Keywords: Ethiopia, Gilgel Gibe, Malaria episodes, Spatiotemporal dynamics

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Background

The level of malaria occurrence is determined by the interactions between *Plasmodium* parasite, the *Anopheles* mosquito vector and the human host. The cycle of interactions, and consequently, the malaria transmission dynamics is determined by the ecological niche even in a small geographical area [1,2]. Hence, anthropogenic interference of the physical environment inevitably modifies the existing equilibrium cycle of the disease transmission pattern [3]. Since malaria transmission intensity varies geographically, the distribution of cases and subsequent morbidity rate may exhibit systematic spatial variation [4]. Therefore, the need for understanding spatial heterogeneity and temporal variations of malaria at micro- geographic level has been emphasized [5-7] for targeted control measure applications.

Currently, Ethiopia is undertaking construction of large hydroelectric dams [8,9] and irrigation schemes of different scales [10-12] as part of developmental activities. This in turn can have impact on vector borne diseases, including malaria as the result of environmental modification. Due to human imposed environmental modifications, risk of malaria has been predicted to increase in East Africa [13,14]; on the other hand, well designed water projects are taught to economically benefit the residents of the dams vicinity and enable the community to strengthen the disease control programmes to overcome the adverse health effects [15,16]. However, the extent of health impact of hydroelectric dams on local communities closer to such dams is less studied.

A couple of local studies indicated increased risks on malaria were associated with proximity to water development schemes [17-19] all those studies were of cross-sectional nature in design to capture temporal influence. However, a follow up study on children two to nine years reported that risk of malaria infection due to proximity to hydro-power dam was insignificant [20]. Still, a few other longitudinal studies [21,22] reported presence of malaria hot spots and heterogeneity of the disease at some relatively wider intervals. Altitudinal rise of the disease has been reported by some studies [23,24], though not reported usually by species. Moreover, studies done elsewhere [25-27] reported that proximity to water sources was not found to be risk factor for malaria, but other factors.

Hence, identification of those at risk areas and seasons provides strategies for targeting timely and locally tailored interventions [28,29]. Quantitative description of the spatio-temporal dynamics has practical implications for the development of malaria control and efficient allocation of resources [30,31]. Spatial investigation of geographic limits of transmission is also used to develop a predictive spatial model of malaria transmission, to facilitate a malaria control strategy based on geographic stratification [32]. To quantify the contribution made by operational intervention and effect of environmental factors, a clear knowledge about the dynamics of malaria in a particular area is important to plan better prevention and management strategies [33]. Therefore, this study was conducted to examine the role of proximity to a hydroelectric dam and altitude on the spatial distribution of *P. falciparium* and *P. vivax*.

Methods

Study setting

This record review was conducted in an area surrounding a man-made lake, Gilgel Gibe Hydroelectric Dam (GGHD), which has been operational since 2004 [34]. The area is a Health and Demographic Surveillance Site (HDSS) [35] which includes surrounding villages within ten km radius of the GGHD with about 50,000 residents used to live in the villages. The area is found within altitude range which favors seasonal malaria transmission [17,20]. Detailed descriptions of the study setting have also been given elsewhere [17,36,37].

Study design

A retrospective record review study was employed using data from local health services (health centers and health posts). This was done by reviewing malaria morbidity records of local health facilities in villages included into the Gilgel Gibe HDSS. Using individual identifiers (name, age, and sex) and village names, malaria positive cases were cross-linked by careful inspection to location and individual records of the HDSS data which had already been geo-referenced (each house in the HDSS has geographic information system (GPS) records).

Source of data

In Ethiopia, malaria cases are treated both clinically and as confirmed malaria in accordance with the National Guideline [38,39], depending on the degree of diagnostic capabilities at different levels of the healthcare system. Both the presumptive and confirmed cases are registered on preformatted registration books (log books) at health care levels and reported both weekly as well as monthly to the next higher level of health management system. The current study included all malaria positive records of the local primary healthcare units that were within the Gilgel Gibe DHSS villages, registered by the primary health care units between September 2003 and August 2011 was reviewed. The timeline consideration was based on data availability and the fact that significant change in the number of malaria cases, such as epidemics, occurs in cyclic fashion from five to eight-year periods in the country [40-42], in order that any fluctuation of such cycle could be captured.

Data collection techniques

A format was prepared on a computer spreadsheet (Excel) to collect the secondary data from log books of

local government primary health care units. Individual level data on malaria morbidity; such as, diagnosis results (negative, species of *Plasmodium* for positives); dates of diagnoses; available demographic data (residence, age, sex) were registered on the computer spreadsheet. All records of malaria cases who visited the health institutions during the designated time were included in the study. Records of cases with incomplete records, such as dates of health service visit, age, address, results of diagnosis, were excluded from the analysis. Furthermore, cases whose names, sex and age did not relate to the geo-referenced data of the Gilgel Gibe HDSS were excluded from the spatial analysis. Accordingly, a total of 10,443 records of malaria positive cases were linked to the geo-referenced HDSS data, which has data on household member list with individual, household and location identities (IDs) as well as GPS readings.

Data management and processing

The data on malaria positive records of the healthcare institutions of the study site were transferred to Excel spreadsheet, checked for completeness (date of diagnosis, test results, patient age and address), coded; then, prepared data of malaria cases were exported to STATA statistical software version 12. Episodes of malaria were considered instead of number of cases for the analysis. The study setting was categorized in to five buffer zones considering distance interval of one kilometer. The altitude of the area was also categorized into six levels as up to 1700, 1701 to 1800, 1801 to 1900, 1901 to 2000, 2001 to 2100, and above 2100 meter above sea level (masl) taking into account the narrow range of this micro-epidemiological setting.

Incidence rate ratio (IRR), which is equivalent to odds ratio in the Poison regression, was estimated using Discrete Poisson model for the buffer zones and for the altitudinal levels. The numbers of base population in the buffer zones and in the ranges of altitude were incorporated as an offset variable to adjust for the underlying population density while computing the IRRs among both the buffer zones and ranges of the altitude. Furthermore, the inter-annual trend of the malaria episodes over the study years considered was analyzed both for all positive cases and for *P. vivax* malaria relative to *P. falciparium* using the IRR to detect change in magnitude of the malaria episodes by years relative to the initial year.

Ethical considerations

Ethical clearances were obtained from the Addis Ababa University College of Health Sciences Ethical Review Board and Oromia Regional Health Bureau Ethical Clearance Committee. Jimma Zone Health Office and the respective District Health offices of the study areas as well as local administrators were communicated by formal letters written from the School of Public Health of the Addis Ababa University and Oromia Regional Health Bureau. Individual information was kept confidential and the names of individuals were removed from data and identified only by identification numbers and the results were communicated in an aggregated manner.

Results

A total of 53,624 malaria episodes were recorded in the Gilgel Gibe HDSS site over a period of eight years of which 25,605 (47.7%) were records of clinical malaria and 28,019 (52.3%) were confirmed malaria episodes. Of the positive cases, *P. falciparium, P. vivax and* mixed *species* constituted 60.4%, 33.6% and 6.0% respectively. Only those records managed to be linked with location identification of the Gilgel Gibe HDSS (10,443 episode records) were analyzed for spatial distribution of the diseases (Table 1) while all the confirmed positive malaria records were considered in the temporal analysis.

The species composition of the geo-referenced malaria episodes were *P. falciparium* (69.2%), *P. vivax* (22.6%) *and mixed species* (8.2). Generally, the contribution of *P. falciparium* was higher near the GGHD and proportion of *P. vivax* exhibited increment with distance from the GGHD. Overall, 38.4% of the episodes were recorded in a distance of less than one kilometer radius of GGHD of which *P. falciparium* and *P. vivax* accounted 81.0% and 10.0% respectively. In the buffer zone one to two kilometer radius of the GGHD, where about a quarter of the malaria episodes were recorded, *P. falciparium* contributed 68.2% while the proportion of *P. vivax* was 22.5%. In the buffer zone from two to three kilometers radius *P. falciparium* and *P. vivax* accounted for 62.7% and 27.8% respectively. The proportions of *P. falciparium* in the buffer zones from three to four and four to five kilometers were 58.9% and 47.6% while that of *P. vivax* were 34.8% and 48.3% respectively. Beyond five kilometers, the proportion of *P. falciparium* showed sharp decline to 7.3% while that of *P. vivax* rose to 91.8%.

Distribution of malaria episodes showed different patterns within species as well among the buffer zones. Unlike to *P. vivax* (18.1%), 46.4% of the *P. falciparium* and 39.4% of mixed species episodes were registered within one kilometer radius of the GGHD.

The proportions of *P. falciparium* and *P. vivax* recoded in the buffer zone range from one to two and two to three kilometers radius of GGHD were similar, which were 26.5% and 14.8% for *P. falciparium* and 26.7% and 20.0% for *P. vivax* respectively. On the other hand, only less than four in ten (3.6%) cases of *P. falciparium* but recognizable proportion (19.5%) of the *P. vivax* episodes were recorded beyond three kilometers radius of the GGHD.

Only less than 0.9% of the malaria episodes were registered to occur in the lower altitude of up to 1700 meter above sea level (masl). Majority (79.2%) of the malaria episodes were registered in the altitude range

Table 1 Distribution of malaria cases by sex, distance from GGHD, altitude and *Plasmodium* species, southwest Ethiopia, September 2003 to August 2011

Variables	Categories	Diagnosis (species of *Plasmodium*), N (%*)			Total
		P. falciparum	*P. vivax*	Mixed	
Distance	< 1 km	3,250 (45.0)	427 (18.1)	336 (39.3)	4,013 (38.4)
	1 to 2 km	1,890 (26.2)	629 (26.6)	261 (30.5)	2,780 (26.6)
	2 to 3 km	1,180 (16.3)	473 (20.0)	167 (19.5)	1,820 (17.4)
	3 to 4 km	661 (9.2)	395 (16.7)	68 (8.0)	1,124 (10.8)
	4 to 5 km	243 (3.4)	228 (9.7)	21 (2.5)	492 (4.7)
	> 5 km	2 (0.03)	210 (8.9)	2 (0.2)	214 (2.1)
Altitude	≤ 1700 m	18 (0.3)	74 (3.1)	5 (0.6)	97 (0.9)
	1701-1800 m	5,796 (80.2)	1,755 (74.3)	716 (83.7)	8,267 (79.2)
	1801-1900 m	857 (11.9)	348 (14.7)	77 (9.0)	1,282 (12.3)
	1901-2000 m	302 (4.2)	115 (4.9)	37 (4.3)	454 (4.4)
	2001-2100 m	137 (1.9)	35 (1.5)	15 (1.8)	187 (1.8)
	>2100 m	116 (1.6)	35 (1.5)	5 (0.6)	156 (1.5)
Age (year)	< 5	651 (9.0)	258 (10.9)	85 (9.9)	994 (9.5)
	5-9	968 (13.4)	345 (14.6)	114 (13.3)	1,427 (13.7)
	10-14	1,098 (15.2)	370 (15.7)	116 (13.6)	1,584 (15.2)
	15 +	4,509 (62.4)	1,389 (58.8)	540 (63.2)	6,438 (61.7)
Sex	Male	4,032 (55.8)	1,360 (57.6)	450 (52.8)	5,842 (56.0)
	Female	3,194 (44.2)	1,002 (42.4)	404 (57.2)	4,600 (44.1)
Total		7,226 (100)	2,362 (100)	855 (100)	10,443 (100)
		69.2	22.6	8.2	100

*Percentage within diagnosis.

from 1701-1800 masl where 80.2% of the *P. falciparum* and 74.3% of *P. vivax* malaria episodes were recorded and the composition of *P. falciparum* and *P. vivax* were 70.1% and 21.2% respectively. The next larger number (12.3%) of malaria episodes was registered in the altitude range from 1801-1900 masl. In this altitude range, 11.9% and 14.3% *P. falciparum* and *P. vivax* were recorded and the proportions contributed by *P. falciparum* and *P. vivax* were 66.9% and 27.2% respectively (Table 1).

As distance increases from the GGHD, the occurrence of *P. falciparum* malaria increases significantly up to five kilometers (P <0.001), controlling the effects of altitude, age and gender (Table 2). The *P. falciparum* malaria was 3.8, 5.1, 3.7 and about 3 times more likely to occur in the buffer zones from one to two km, two to three km, three to four km and four to five km respectively compared to the occurrence of *P. falciparum* malaria within one km buffer zone of the GGHD.

Increasing altitude showed negative correlation with the occurrence of *P. falciparum* malaria up to 1900 masl, but it exhibited positive association as altitude increases above 1900 masl and the correlation was significant (P <0.01). Altitudes in the range of 1901-2000 m, 2001-2100 and above 2100 were 1.6, 2.5 and 2.6 times more likely to increase the risk of *P. falciparum* malaria compared to altitude up to 1700 masl. Regarding to the risk of *P. falciparum* infection among different age groups, children in the age range ten to fourteen years were affected more significantly than the other age groups (P = 0.04). The risk of *P. falciparum* malaria was seen to be significantly higher among males than females (P <0.01) when the effects of distance from the GGHD, altitude and age are controlled (Table 2).

On the other hand, as distance from the GGHD increases, the occurrence of *P. vivax* malaria increases consistently and significantly (P <0.001), keeping the effects of altitude and gender constant. The occurrence of malaria in the buffer zones from one to two km, two to three km, three to four km, four to five km and beyond five km was 9.8 times, 13.6 times, 11.9 times, 52.0 times and 68.7 times more likely to occur compared to the occurrence of *P. vivax* malaria in the buffer zone within one km radius of the GGHD. However, increasing altitude was negatively and significantly associated with the occurrence of *P. vivax* malaria (P <0.001).

Children under the age of five years were found to be more affected by *P. vivax* malaria than the other age categories. The risk of *P. vivax* among children five to nine

Table 2 Effects of proximity to a dam and altitude on *Plasmodium falciparum* malaria southwest Ethiopia, September 2003 to August 2011

Variables	Categories	IRR	Std. Err.	P Value	95% C.I.	
					Lower	Upper
Buffer zones relative to GGHD	< 1 km	1				
	1-2 km	3.82	0.07	< 0.001	3.68	3.96
	2-3 km	5.10	0.12	< 0.001	4.88	5.34
	3-4 km	3.73	0.10	< 0.001	3.53	3.93
	4-5 km	2.97	0.13	< 0.001	2.72	3.24
	>5 km	1.04	0.15	0.81	0.78	1.37
Altitude in meters	≤ 1700	1				
	1701-1800	0.03	0.01	< 0.001	0.02	0.04
	1801-1900	0.93	0.17	0.71	0.65	1.33
	1901-2000	1.61	0. 30	0.01	1.12	2.31
	2001-2100	2.51	0.47	< 0.001	1.74	3.63
	2101-2230	2.64	0. 50	< 0.001	1.82	3.82
Age (year)	< 5	1				
	5-9	1.05	0.04	0.19	0.98	1.12
	10-14	1.10	0.04	< 0.01	1.03	1.17
	15 +	1.04	0.03	0.14	0.99	1.10
Sex	Male	1				
	Female	0.96	0.01	0.01	0.93	0.99

years, ten to fourteen years and adult age groups was less by about 9%, 16% and 11% respectively compared to the risk of *P. vivax* in the under five years of age children. There was also higher chance of *P. vivax* malaria risk among males compared to females keeping the effects of altitude, distance from GGHD and age constant (Table 3).

Overall, there was reduction of about 70% and 60% of malaria episodes in the years 2004/5 and 2005/6 respectively compared to that of 2003/4. However, since 2006/7 increment of malaria episodes was evident up to 2010. In 2006/7 the malaria episode increased about 14.9% as compared to 2003/4. In the following three years, the increment of malaria episodes was 2.3 times, 2.9 times and 4.1 times more likely higher in the years 2008/9, 2009/10 and 2011 as compared to the observed episodes of malaria in the year 2003/4. In the year 2011, the malaria episodes showed reduction of 14% which was statistically insignificant (P = 0.30).

On average, *P. vivax* was 52% lower than *P. falciparium* over the study period considered. The rate of *P. vivax* increments were 130% and 40% in the years 2004/5 and 2005/6 respectively as compared to *P. falciparium* episodes those years. In the years 2006/7, 2007/8 and 2010/2011 there were 60% *P. vivax* rate increments compared to *P. falciparium* during the same time. On the other hand, in the years 2008/9 and 2009/10, there were reductions of *P. vivax* episodes rate by 10% and 16% respectively though the reduction was insignificant in 2008/9 (P = 0.06) (Table 4).

Discussions

This study assessed malaria transmission intensity level spatially within the proximity of GGHD taking into account possible influence of altitude on episodes of *P. falciparium* and *P. vivax* malaria. Temporal trend of all positive episodes of malaria over an eight year period was also examined.

There was variation of species with respect to distance from the GGHD and altitudinal levels. From descriptive analysis, it was apparent that most of *P. falciparium* malaria have occurred nearer to the Dam, within two kilometer radius of GGHD and showed reduction with distance from Dam. This finding is in line with previous local studies [18,43,44] though the earlier findings were not reported in terms of *plasmodium species* composition. However, adjusting for the population density revealed the risk of *P. falciparium* infection was higher beyond one km radius of the Dam, especially in the buffer zone two to three km of the Dam.

The spatial cluster of *P. falciparium* in a small geographical area is also compatible with other findings [1,22,45,46]. However, the current finding is in contrast to previous local findings, where the risk difference for *P. falciparium* between children who lived within three kilometer of GGHD and beyond eight kilometers was insignificant

Table 3 Effects of proximity to a dam and altitude on *Plasmodium vivax* malaria southwest Ethiopia, September 2003 to August 2011

Variables	Categories	IRR of *Pv*	Std. Err.	P Value	95% C.I.	
					Lower	Upper
Buffer zones relative to GGHD	< 1 km	1				
	1-2 km	9.82	0.32	< 0.001	9.22	10.47
	2-3 km	13.56	0.50	< 0.001	12.61	14.58
	3-4 km	11.94	0.49	< 0.001	11.02	12.93
	4-5 km	52.00	2.10	< 0.001	48.03	56.29
	>5 km	68.72	3.46	< 0.001	62.26	75.85
Altitude in meters	≤ 1700 m	1				
	1701-1800	0.02	0.001	< 0.001	0.02	0.01
	1801-1900	0.44	0.03	< 0.001	0.38	0.50
	1901-2000	0.64	0.05	< 0.001	0.55	0.75
	2001-2100	0.51	0.06	< 0.001	0.41	0.64
	>2100 m	0.54	0.06	< 0.001	0.43	0.68
Age (year)	< 5	1				
	5-9	0.91	0.04	0.03	0.83	0.99
	10-14	0.84	0.04	< 0.001	0.78	0.92
	15 +	0.89	0.03	0.001	0.83	0.95
Sex	Male	1				
	Female	1.04	0.02	0.04	1.00	1.09

Table 4 Trends of confirmed malaria by year and Species southwest Ethiopia, September 2003 to August 2011

Plasmodium species	Year	IRR	Std. Err.	P value	(95% C. I.)	
All positive	2003/4	1				
	2004/5	0.30	0.02	< 0.001	0.27	0.34
	2005/6	0.40	0.02	< 0.001	0.36	0.44
	2006/7	1.15	0.04	< 0.001	1.07	1.24
	2007/8	2.26	0.08	< 0.001	2.11	2.41
	2008/9	2.87	0.09	< 0.001	3.00	3.06
	2009/10	4.08	0.13	< 0.001	3.84	4.34
	2010/11	0.96	0.04	0.30	0.89	1.04
P. vivax in reference to P. falciparum	During the whole period	1				
		0.48	0.02	< 0.001	0.43	0.52
Rate ratio	2003/4	1				
P. vivax to	2004/5	2.30	0.20	< 0.001	1.95	2.72
P. falciparum	2005/6	1.41	0.12	< 0.001	1.19	1.67
	2006/7	1.57	0.10	< 0.001	1.39	1.78
	2007/8	1.59	0.09	< 0.001	1.42	1.77
	2008/9	0. 90	0.05	0.06	0.80	1.00
	2009/10	0.84	0.05	< 0.01	0.76	0.94
	2010/11	1.61	0.10	< 0.001	1.42	1.83

[17,20], implying proximity to water bodies alone does not increase risk of the disease. Again, another study reported that distance to water body was reported not to be significantly associated with prevalence of *P. falciparium* malaria [26].

However, the magnitude of *P. falciparium* malaria exhibited increment with altitude above 1900 masl, implying the up scrolling of malaria to highland areas possibly due to change in climate variables as had already been evidenced elsewhere [14,24]. The fact that *P. falciparium* prevails in the area mainly for short period of time following heavy rainfall from September to November usually in the form of epidemics [47], might have played a role in increasing the number of cases with altitude, as more susceptible individuals are exposed to the infection for relatively shorter duration due to the wave of epidemics.

On the other hand, *P. vivax* malaria episodes exhibited decrease as altitude increased, especially starting from 1800 masl; however, it showed persistently significant increase as distance increases from GGHD (P <0.001). The decrement of *P. vivax* malaria episodes with increasing altitude was similar to another finding [48]. The proportional increment of *P. vivax* malaria episodes with the distance from the Dam was in agreement with a previous local study which indicated that, unlike *P. falciparium* malaria, more *P. vivax* malaria among distant communities was comparable to those close to a large dam [9]; however, the underlying rationale is not clear and needs further explorations as the *P. vivax* has been given less attention and under studied [49] in spite of the fact that it poses potential severe health consequences [50-52].

Pertaining to the trend of the disease, *P. falciparium* malaria significantly increased from 2006/7 to 2009/10 (P <0.001), compared to the 2003/4, but it was lower in the years 2004/5, 2005/6 and 2010/11. Such persistent increment of the episodes of *P. falciparium* could possibly be due to resistance development by malaria vector mosquitoes to insecticides that had been in use for indoor residual spraying (IRS) in the country for about half of a century until vector resistance to DDT was detected in 2007 [53-55]. The noticed decline of *P. falciparium* malaria episodes after 2010 could possibly be due to the replacement of old LLINs in 2009, and shifting of insecticide used for IRS in 2010 to deltamethrin or bendiocarb insecticides [53], such coincidence of interventions followed by a sharp drop of malaria episodes, had also been reported by other studies [56-61] whereas weakened interventions and development of resistances of the vector to insecticides and the parasite to drugs have been documented to associate with the resurgence of the diseases [62].

The decline of *P. falciparium* malaria episodes between 2004/5 and 2005/6 might also be attributed to the scale up of interventions, including LLITNs [63,64] following the large scale malaria epidemics of 2003 [65,66] implying the need for monitoring the major malaria intervention tools such as IRS & LLITNs, the effectiveness.

Conclusions

There were both temporal and spatial variations of malaria episodes during the study period. The rise of malaria episodes between the years 2008 and 2010 was due to *P. falciparium* where the contribution of *P. vivax* especially during 2009 and 2010 was lower compared to 2003/4. Spatial distribution of the two species was different that though both exhibited increase with distance from the Dam, *P. vivax* episodes increased by many folds constantly as distance increases from the Dam. However, *P. vivax* episodes were limited mainly to relatively lower altitude range. Regarding to the increment of *P. falciparium* with altitude and that of *P. vivax* with distance from reservoir of dams, further exploration is needed.

Given the higher proportion of *P. falciparium* that contributed to about two-third of the malaria episodes of the area, and the fact that still more than two-third of the *P. falciparium* occurred within two kilometers radius of the GGHD, it demands a vigilant monitoring of the disease in the area and sustainable interventions. Density of the base population needs to be considered while conducting spatial analysis of diseases, which is mostly overlooked.

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

LS participated in the study design, undertook the field study, analyzed data and wrote the manuscript. WD participated in the study design, revision of the manuscript and facilitation of administrative issues. AA participated in the study design, revision of the manuscript and facilitation of administrative issues. All the authors have also read the manuscript and approved it to submit for publication.

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3. Paper three

ORIGINAL ARTICLE (27 Nov. 2014)

CORRELATION OF CLIMATE VARIABILITY AND MALARIA: A RETROSPECTIVE COMPARATIVE STUDY, SOUTHWEST ETHIOPIA

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ABSTRACT

BACKGROUND: Climatic variables can determine malaria transmission dynamics. To see the correlation between malaria occurrence and climatic variables, records of malaria episodes over eight years period were analyzed incorporating climatic variables around Gilgel-Gibe Hydroelectric Dam and control sites.
METHODS: Records of 99,206 confirmed malaria cases registered between 2003 and 2011 were analyzed along with local meteorological data of the same duration. Data were analyzed with SPSS statistical software version 20 for Windows. Spearman correlation coefficient was estimated as a measure of the correlation.
RESULTS: The major peaks of malaria prevalence were observed following the peaks of rainfall in the Gilgel-Gibe Hydroelectric Dam site. In the control site, the peaks of malaria in some years coincided with the peaks of rainfall, and the pattern of rainfall was relatively less fluctuating. Mean rainfall was negatively correlated with number of malaria cases at lags of 0 and 1 month, but positively correlated at lags of 2 to 4 months. Mean relative humidity showed significant positive correlations at lags of 3 to 4 months. Monthly mean maximum and minimum temperatures weakly correlated at lags of 0 to 4 months.
CONCLUSIONS: Correlations of malaria and climate variables were different for the two sites; in Gilgel-Gibe, rainfall and relative humidity showed positive correlations. However, in the control area, the correlation of weather variables and malaria records were insignificant. Exploration of additional factors such as vegetation index and physico-chemical nature of mosquito breeding site may improve understanding of determinants of malaria dynamics in the area.
KEYWORDS: climatic variables, correlations, Ethiopia, Gilgel-Gibe, malaria
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INTRODUCTION

Malaria has been a major public health problem and a hindrance to socioeconomic development in Ethiopia (1). Clear knowledge of the driving factors of malaria dynamics in a particular area is crucial for better planning and implementation of prevention and control strategies (2). Trends of malaria and composition *Plasmodia species* vary over time (3-6) due to different factors such as previous climatic factors. Climatic variables determine the dynamics of malaria by limiting the survival and longevity of malaria vectors and the rate of *Plasmodium* development in the vector mosquitoes (3, 7-10).

Some studies underlined that climatic variables partially or fully (11-13) correlated positively with monthly incidence of malaria, whereas others reported different levels of correlation of climatic variables with malaria occurrence in different eco-epidemiological settings (14-16). Brooker et al (17) emphasized that the distribution of malaria is determined by climatic and other geographic factors that affect vector mosquito and *Plasmodium* reproduction. However, still other findings show neither association between the number of malaria cases (18) nor trend of malaria vector populations and climatic variables.

Environmental factors such as changing rainfall patterns, water development projects

and unusual temperature increase can play great roles in malaria transmission dynamics (19). Moreover, anthropogenic disruption of the natural equilibrium of environment inevitably modifies the malaria transmission dynamics (20, 21). Thus, understanding how malaria varies in a particular area as a result of changes in environmental factors is of paramount importance for the planning of malaria control programs (22).

However, the transmission pattern of malaria with climatic variables is less studied in a modified environment, due to human activities, relative to an unaffected area. In this regard, this study assessed and compared trends of malaria for two sites-villages surrounding a hydroelectric power dam (GGHD) and similar control villages without a dam. The study incorporated climatic variables (temperature, precipitation and relative humidity) to see whether these variables play a role in the pattern of malaria prevalence in those sites differently.

MATERIALS AND METHODS

Study settings

This retrospective record review comparative study was conducted in two rural settings: one site near a manmade lake, GGHD, and a control site from an area far from the Lake. Gilgel Gibe Hydroelectric Dam (GGHD) is located 260 km south-west of Addis Ababa, the capital of Ethiopia. On global positioning, the dam is found at 07.4253^0 to 07.5558^0 N and 037.1153^0 to 037.2033^0 E. The area lies within the range of mosquito breeding altitude. Surveys conducted in the area (23-25) have shown that the prevalence of malaria among children was higher by many folds than the national malaria indicator survey results of 2007 (26).

From the District, only two kebeles (smallest administrative units) are found within 10 km radius of the Dam, and those villages (Dogoso and Siba) were considered to be influenced by the Dam. Thus, they were included to the study villages of GGHD. Twenty-seven other kebeles (villages) of Kersa District, excluding Dogoso and Siba, are malarious of which 21 are labeled as high risk villages eight of which designated as control villages. A previous study also indicated that the prevalence of malaria was high in the control site (27). Like GGHD areas, all those villages have health posts staffed with health extension workers; the residents had similar living patterns. Additional description of the study sites was given elsewhere (28) and figure 1 shows the position of the study sites, including small towns in them.

Study design

A retrospective record review of malaria cases and meteorological data of the same duration were carried out. Monthly malaria morbidity records registered between September 2003 and August 2011 in local health facilities pertaining to villages within 10-kilometer radius of Gilgel-Gibe Hydroelectric Dam and in those health facilities of the control sites were analyzed along monthly average climatic variables. The monthly means of both minimum and maximum temperatures, relative humidity and rainfall of local meteorological stations of the two sites were incorporated into the analysis to examine the correlations of malaria and climate variability over the eight years period. As major changes in malaria transmission had been recorded to have occurred in periodic cycle of between 5 and 8 years in the country (14, 29), the time for this study was limited to eight years.

Source of data and sample size

There were eight health posts and three health centres in the GGHD site. In the control site, there were also eight health posts and a health centre. The malaria episodes data were collected from those health institutions within the catchments of GGHD and the control villages. All malaria episode records kept in the health institutions between September 2003 and August 2011 were reviewed. The meteorological data (temperature, humidity and precipitation) of the study sites were sought from the National Meteorological Agency South West Ethiopia Regional Branch.

Data collection techniques

The format was prepared on a computer spreadsheet (excel) to collect secondary data from health institutions of the designated areas. Individual level data on malaria morbidity and mortality were collected from logbooks of the local health institutions. Variables such as diagnosis results (negative, species of *Plasmodium* for positives), dates of diagnosis and available demographic data (residence, age, sex) were captured on the computer spreadsheet. All records of patients who visited health institutions and were treated as malaria patients were included in the study. Records of cases with incomplete or invisible records such as dates of health service visit, age, address, results of diagnosis were excluded from the study.

Data management and processing

Initially, patient records kept in logbooks at the health institutions were recorded on excel spreadsheet separately. Then, data on patient records from different health institutions were checked for completeness, coded and combined on the same spreadsheet. Only a few incomplete records were discarded from the analysis. Daily minimum and maximum climate variables (temperatures, precipitation and relative humidity) were recorded on a computer spreadsheet separately for Gilgel-Gibe and the control sites. For both localities, monthly averages of climatic variables were computed for minimum, mean and maximum values. Then, prepared data of malaria cases and meteorological data were exported to SPSS statistical software version 20 for Windows and linked together using unique identifiers (month, year and location codes). Then, analyses were performed using Spearman correlation coefficient. The graphic presentation of rainfall of the sites against monthly malaria episodes was done with excel.

Ethical considerations

Ethical clearances were obtained from the Addis Ababa University College of Health Sciences Institutional Review Board and the Oromia Regional Health Bureau Ethical Clearance Committee. South-West Regional Branch Meteorological Agency, Jimma Zonal Office and district health offices as well as local administrators were requested through formal letters from the School of Public Health of Addis Ababa University and Oromia Regional Health Bureau for their cooperation and consents. Individual information was kept confidential and the names of individuals were removed from data of health services and identified only by identification numbers. Results were also communicated in an aggregated manner.

RESULTS

A total of 99,206 confirmed malaria cases were recorded over eight years period in both study sites. More than two-third (71.8%) of the cases were from the control site, while 28.2% of them were from Gilgel-Gibe. In spite of inter annual variations, proportion of *P. falciparum* slightly increased over time in Gilgel-Gibe; however, the *P. falciparum* proportion significantly decreased relative to *P. vivax* in the control sites (Table 1).

Table 1: Distribution of confirmed malaria cases by study sites, *Plasmodium* species and years of health service visits, southwest Ethiopia, September 2003 to August 2011

Site	Species		2003	2004	2005	2006	2007	2008	2009	2010	2011	Total
Gilgel-Gibe	PF	No	910	665	443	571	2116	3762	5432	2271	759	16929
		%	48.8	47.9	61.0	52.6	56.0	63.3	74.2	50.4	54.0	60.4
	PV	No	328	587	237	443	1619	2177	1825	1752	442	9410
		%	17.6	42.3	32.6	40.8	42.9	36.6	24.9	38.9	31.4	33.6
	PM	No	627	136	46	71	43	7	63	482	205	1680
		%	33.6	9.8	6.3	6.5	1.1	0.1	0.9	10.7	14.6	6.0
	Subtotal	No	**1865**	**1388**	**726**	**1085**	**3778**	**5946**	**7320**	**4505**	**1406**	**2801**
Control	PF	No	1640	3006	6286	2557	5315	6669	5443	6275	43	37234
		%	76.5	61.2	54.2	58.6	53.0	48.4	53.0	45.0	23.2	52.3
	PV	No	467	1826	5096	1733	4493	6785	4593	6696	140	31829
		%	21.8	37.2	44.0	39.7	44.8	49.3	44.7	48.1	75.7	44.7
	PM	No	37	79	211	71	211	316	235	962	2	2124
		%	1.7	1.6	1.8	1.6	2.1	2.3	2.3	6.9	1.1	3.0
	Subtotal	No	**2144**	**4911**	**115**	**4361**	**10019**	**13770**	**10271**	**13933**	**185**	**71187**
Total	PF	No	2550	3671	6729	312	7431	10431	10875	8546	802	54163
		%	63.6	58.3	54.6	57.4	53.9	52.9	61.8	6.3	50.4	54.6
	PV	No	795	2413	5333	2176	6112	8962	6418	8448	582	41239
		%	19.8	38.3	43.3	40.0	44.3	45.5	36.5	45.8	36.6	41.6
	PM	No	664	215	257	142	254	323	298	1444	207	3804
		%	16.6	3.4	2.1	2.6	1.8	1.6	1.7	7.8	13.0	3.8
	Total	No	**4009**	**6299**	**123**	**5446**	**13797**	**19716**	**17591**	**18438**	**1591**	**99206**

PM: Plasmodium mixed; **PF**: plasmodium falciparum; **PV**: plasmodium vivax

Eight years averages of maximum, mean, and minimum climatic variables of the study sites are summarized in table 1. The average maximum rainfall of the control site was higher than the Gilgel-Gibe site (20.2 mm vs 10.7 mm), whereas the average mean rainfall was similar in both sites with same standard deviations. The average mean relative humidity of the control site was slightly higher than that of Gilgel-Gibe site. However, the means of maximum and minimum relative humidity of both study sites were the same. On the other hand, both means of maximum and minimum temperatures were slightly higher in control sites, with higher variability of the latter (SD: 2.7 vs 2.0) in the control site (Table 2).

Table 2: Monthly averages of eight years climatic variables of study sites, southwest Ethiopia, September 2003 to August 2011

Weather variables		Gilgel-Gibe Mean (SD)	Control Mean (SD)	Overall Mean (SD)
Rainfall (mm)	Maximum	11.9	20.2 (3.6)	20.2
	Mean	3.3 (2.9)	3.7 (3.6)	3.3 (3.2)
Relative humidity (mmHg)	Maximum	76.7	76.8	76.8
	Mean	54.2 (12.7)	55.8 (11.9)	55.2 (12.2)
	Minimum	24.7	24.7	24.7
Temperature (C°)	Maximum	27.40 (2.6)	28.0 (2.1)	27.8 (2.2)
	Mean	19.3 (1.2)	19.9 (1.1)	19.6 (1.2)
	Minimum	11.2 (2.0)	11.8 (2.7)	11.5 (2.5)

The rainfall pattern in Gilgel-Gibe site showed several rises that lasted for short durations, whereas that of the control site exhibited a gradual rise and relatively minimal variations. At the Gilgel-Gibe site, the major peaks of malaria prevalence were observed following the peaks of rainfall. In the control site, the peaks of malaria prevalence in some years coincided with the peaks of rainfall, and the pattern of rainfall relatively fluctuated less and was almost continuous in quarters of the year. Between December 2007 and March 2008, rainfall reached the highest peak and malaria prevalence climax was noticed after the rainfall peak. It is evident from the linear trend line that malaria prevalence increased more in the Gilgel-Gibe site than in the control site, despite the higher malaria prevalence observed in the control site over the entire study period (Fig 1).

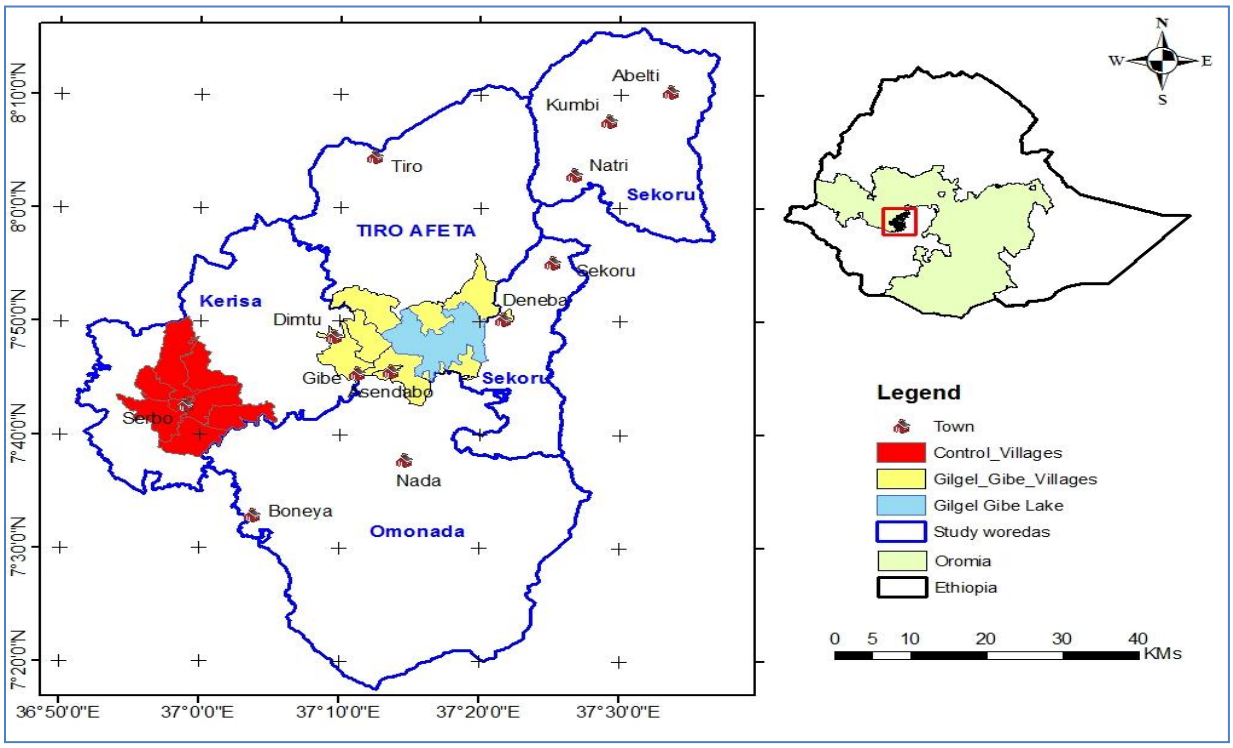

***Figure 10**: Map of the Study sites within Oromia Regional State of Ethiopia*

Raw data source: CSA & JU-IHSR

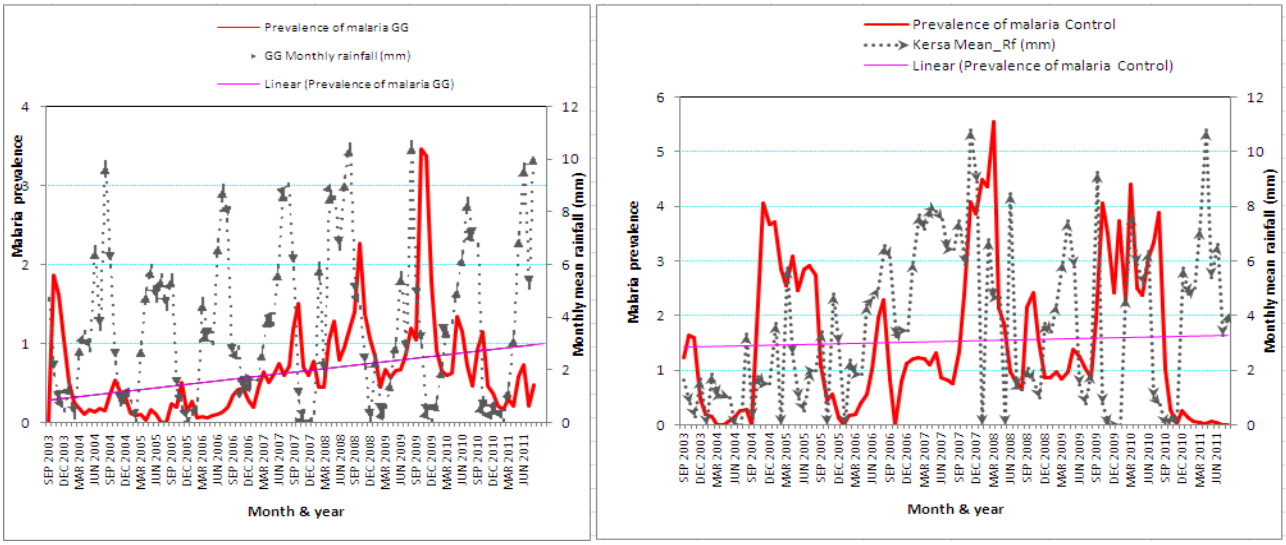

***Figure 2**: Prevalence of malaria and monthly mean rainfall by quarter and year, southwest Ethiopia, September 2003-August 2011*

Monthly mean rainfall and number of monthly malaria cases showed negative correlation at lag of 0 and 1 month, but positive correlation at lags of 2 to 4 months. The correlation increased as the number of lags increased from 2 to 4 months although the positive correlation of rainfall with the number of malaria was insignificant at all the lags. Monthly mean relative humidity showed positive correlation with number of malaria from lag of 0 to 4 months and the strength of the correlation increased as the number of lags increased. There were significant correlations at lags of 3 (P = 0.02) and 4 (P = 0.03) months. Monthly average maximum temperature and the number of malaria cases showed negative, but weak and insignificant correlation at all lags of 0 to 4 months. Again, monthly average minimum temperature exhibited a negative correlation with number of malaria cases up to lags of 2 months, but positive correlation at lags of 3 and 4 months. The correlation was of incremental nature with number of lag months. However, the correlation was weak and insignificant (Table 3).

Table 3 Correlation between monthly confirmed malaria cases and mean monthly climatic variables by study sites, Southwest Ethiopia, September 2003-August 2011

Monthly mean Climate variables	Lag-months	Gilgel-Gibe Spearman's r	Control Spearman's r	Overall Spearman's r
Rainfall	0 Months	0.0060	-0.1959	-0.076
	1 Month	0.1278	-0.1473	-0.003
	2 Months	0.3589	-0.1495	0.065
	3 Months	0.3270	-0.0806	0.078
	4 Months	0.2304	0.0494	0.108
Relative humidity	0 Months	0.0133	-0.2154	0.006
	1 Month	0.1591	-0.1099	0.086
	2 Months	0.4182	-0.0381	0.133
	3 Months	0.2820	0.0789	0.171
	4 Months	0.2174	0.1184	0.157
Maximum temperature	0 Months	-0.0983	0.1723	-0.020
	1 Month	-0.2044	0.0966	-0.072
	2 Months	-0.2350	0.0203	-0.136
	3 Months	-0.2233	-0.0894	-0.130
	4 Months	-0.1874	-0.1099	-0.116
Minimum temperature	0 Months	-0.261	-0.1108	-0.123
	1 Month	-0.0808	-0.0611	-0.052
	2 Months	0.0191	-0.0535	-0.031
	3 Months	0.1135	0.0441	0.001
	4 Months	0.1676	0.1027	0.039

Similarly, there was a negative correlation between average number of monthly Pf malaria cases and rainfall at 0 and 1 month lags, and positive, but weak correlation from 2 to 4 months lags. Relative humidity showed negative correlation at 0 month, positive and increasing correlation from 1 to 4 months lags. At the Gilgel-Gibe site, moderate correlations were observed at months 2 and 3 lags both with rainfall and relative humidity in Gilgel-Gibe site. There were only weak positive correlations at month 4 for rainfall and months 2 through 4 for relative humidity at the control site.

The maximum and minimum average temperatures were, in most cases, negatively and weakly correlated with the monthly number of Pf malaria cases. The average minimum temperature was weakly but positively correlated in Gilgel-Gibe site from 1 to 4 months lags. In the control site, the average maximum temperature was positive, but insignificantly correlated with the monthly number of malaria cases at lag of 0 months. The correlations were not apparent when combined for both sites and there were very weak correlations when analyzed for the two sites together (Table 4).

Table 4 Correlation between average monthly *Plasmodium falciparum* malaria cases and mean monthly climate variables by study sites, southwest Ethiopia, September 2003-August 2011

Monthly mean Climate variables	Lag-months	Gilgel-Gibe Spearman's r	Control Spearman's r	Overall Spearman's r
Rainfall	0 Months	0.0077	-0.1400	-0.0860
	1 Month	0.1356	-0.1004	-0.0217
	2 Months	0.3889	-0.0936	0.0698
	3 Months	0.3778	-0.0155	0.1098
	4 Months	0.2096	0.0938	0.1139
Relative humidity	0 Months	0.0773	-0.1812	-0.0053
	1 Month	0.1708	-0.0295	0.1031
	2 Months	0.2558	0.0662	0.1784
	3 Months	0.2855	0.1682	0.2366
	4 Months	0.1730	0.1885	0.2006
Maximum temperature	0 Months	-0.0029	0.1018	0.0312
	1 Month	-0.0249	-0.0136	-0.0204
	2 Months	-0.1514	-0.1028	-0.1062
	3 Months	-0.1056	-0.1865	-0.1165
	4 Months	-0.0539	-0.1627	-0.0873
Minimum temperature	0 Months	-0.2162	-0.1190	-0.1446
	1 Month	0.0449	-0.6549	-0.0321
	2 Months	0.0030	-0.7122	-0.0040
	3 Months	0.0493	-0.6157	0.0640
	4 Months	0.0325	-0.2954	0.0943

DISCUSSIONS

This study examined the correlation between three major climatic variables which are known to affect the dynamics of malaria (rainfall, relative humidity and temperature) and both monthly number of all types of confirmed malaria as well as *P. falciparum* malaria. Although the Gilgel_Gibe site is situated at slightly lower altitude range, both sites are found within malaria risk altitude ranges (24, 27), the number of malaria cases was higher in the control site possibly due to plenty of rainfall over the period considered compared to Gilgel-Gibe site. The correlation of persistent malaria transmission with such continuous higher level of rainfall is in agreement with the prediction model of malaria transmission in Africa (20, 30). However, it is inconsistent with the finding of a local study that reported that risk of malaria was found to be higher at lower altitude (31).

Overall monthly mean rainfall showed positive, but weak, correlation at lag-months 2 to 4, and relative humidity has shown also a weak positive correlation from 0 to 4 months lag which is similar to estimated epidemic prediction of 2 to 4 months after rainfall in East Africa (32). However, when separately analyzed by study site, both rainfall and relative humidity were positively correlated with prevalence of malaria in the Gilgel-Gibe, whereas negative correlation was observed in the control site up to three-months lag for rainfall, two-months lag for relative humidity, a month lag for minimum temperature and 0 to 4 months lag of maximum temperature. Such negative correlation of temperature and occurrence of malaria cases was reported by an-

other study as well (33). The site-specific correlation of malaria prevalence and climate variables at different time lags in different eco-epidemiological settings were also indicated by other studies (14, 15, 34, 35). On the other hand, the absence or weak correlation of the climate variables with malaria occurrence was highlighted by certain studies (18, 36), whereas still other studies underline the strong correlation of climate variables with number of malaria cases (11, 12, 37-40). The modest correlation of rainfall and relative humidity with prevalence of malaria in the Gilgel-Gibe site was at two to three months lag which was congruent to a local study (41). Other studies reported correlations of shorter lags (42, 43); however, another local study had indicated more time lags (14).

Furthermore, other studies (44-46) indicated that the dynamics of malaria is determined by multiple contributing factors; the correlation between malaria and climatic variables is not always a direct one, and reliance on only climatic variables for prediction of malaria occurrence may not be sufficient. The correlation between climate variables and malaria occurrence simply indicates the presence of a linear relationship between them, but the absence of correlation does not prove the absence of association of climate variables with occurrence of malaria. In a setting where minimal variability of temperature prevails and existing conditions are favorable for malaria, it may be difficult to distinguish the role of fluctuation of climatic parameters on malaria prevalence (16). Moreover, eco-epidemiological variability and species of malaria vector difference in different settings impose additional uncertainty on the generalizability of findings to other settings. Therefore, consideration of local specific factors is important in the battle against malaria.

Possible limitations of this study were use of some data from nearby stations and use of imputation methods where missing of data were encountered. Temperature and humidity data for the control site were obtained from Jimma Station, and for the Gilgel-Gibe site, humidity data of Sokoru Station were used. Both Jimma and Sokoru stations are close to the control and the Gilgel-Gibe study sites respectively. Thus, they are expected to have similar weather conditions as there is no major geographical difference in terms of altitude and coverage of vegetation between those stations and the respective study sites. In addition, imputation method was used to fill the missed humidity data of three years using the average of the respective months. Those conditions might affect the findings of this study to a certain extent.

In conclusion, correlations of malaria and climate variables were different for the two sites. In Gilgel-Gibe, rainfall and relative humidity showed positive correlations and modest correlations were seen during 2 to 3 months lags. In the control area, insignificant positive correlation of rainfall and relative humidity was seen at 4 months and 3 to 4 months lags respectively. Mean maximum and minimum ambient temperature indicated weak correlations in both sites. This implies that in Gilgel-Gibe, rainfall and relative humidity are driving forces behind malaria at 2 to 3 months lags. On the other hand, the weak/absence of correlation does not prove absence of the association between malaria and climate variables; it simply implies absence of linear relationship between them. There is a need to consider additional factors such as a normalized difference vegetation index (NDVI) and the physico-chemical nature of the water bodies (mosquitoes breeding sites) in assessing malaria risk factors of a locality that play a role in the rate-limiting of the dynamics of malaria.

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4. Paper four

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RESEARCH Open Access

Predictors of long-lasting insecticide-treated bed net ownership and utilization: evidence from community-based cross-sectional comparative study, Southwest Ethiopia

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Abstract

Background: Malaria is the notorious impediment of public health and economic development. Long-lasting insecticide-treated bed nets/insecticide-treated bed nets (LLINs/ITNs) are among major intervention strategies to avert the impact the disease. However, effectiveness of LLINs/ITNs depends on, *inter alia*, possessing sufficient number, proper utilization and timely replacement of nets. Thus, the World Health Organization (WHO) recommends surveys to evaluate possession and proper use of LLINs/ITNs by households.

Methods: A cross-sectional comparative household survey was conducted during peak malaria transmission season using interviewer-introduced questionnaires in southwest Ethiopia. A study site was selected from villages around a man-made lake, Gilgel-Gibe (GG) and a control site, with similar geographic and socio-economic features but far away from the lake, was identified. A total of 2,373 households from randomly selected cluster of households were included into the study and heads/spouses of the households responded to interviews. Binary and multinomial logistic regressions were used to identify predictors of LLIN ownership and utilization.

Results: LLIN/ITN ownership among the study populations was 56.6%, while 43.4% of households did not own a net. A higher proportion of households in GG reported owning at least one LLIN/ITN compared to control village (OR = 2.2, P <0.001) and more households in GG reported having only one LLIN/ITN in contrast to households in the control village (OR = 2.1, P <0.001). The mean number of LLINs/ITNs owned was 1.6 for GG residents and 1.8 for control village with a mean difference of −0.26 (95% CI: −0.34, -0.19). The age of household heads, household relative wealth index (RWI), distance to nearest health service and accessibility to transportation showed a significant association with ownership of LLINs/ITNs. The probability of owning two or more LLINs/ITNs was positively associated with age of household head. Marital status of household heads, RWI, distance to nearest health service, accessibility to transport, residence and household size showed a significant association with utilization of LLINs/ITNs.

Conclusion: Attention needs to be given to the poor, distant and inaccessible households in the efforts of malaria intervention programmes, such as free distribution of LLINs/ITNs. Well-tailored information, education and communication is needed to address the problem of non-users.

Keywords: Gilgel-gibe, Long-lasting insecticide-treated bed nets/insecticide-treated bed nets, Malaria, Ownership, Possession, Utilization

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Background

Until recently, malaria has been a major public health problem in Ethiopia, causing millions of cases and thousands of deaths annually [1,2]. Present malaria control strategies involve early diagnosing and treating infected individuals and reducing human mosquito contact rates through vector control efforts [3]. Long lasting insecticide treated bed nets/insecticide treated bed nets (LLITNs/ITNs) are considered to be one of the major components of the selective vector control strategies in Ethiopia [4,5]. Since, 2005 the government of Federal Democratic Republic of Ethiopia embarked on a scaling up of LLINs/ITNs where the coverage was planned to be 100% by the end of 2007 inline to the Roll Back Malaria recommendation of universal coverage [6,7].

However, bed nets as a tool for malaria control can present challenges, such as coverage, proper use and replacement of old and torn nets [8]. The possible shift in local malaria epidemiology prompts also the need for evaluation of their proper use and effectiveness in ensuring the long term benefit of this control method [9-11]. According to the Ethiopian malaria indicator survey of 2007, the coverage in sampled malarious areas was 66.6% for households with one bed net and among those LLINs/ITNs owning households only 53.2% of family members had slept under a LLIN/ITN the previous night of the survey [12]; this shows that both coverage and utilization were below the set targets [13,14]. Also, studies conducted in eastern and western part of the country showed that the coverage and utilization of existing LLINs/ITNs even by the vulnerable members (pregnant women and children) of the households were still very low [15,16].

According to local health offices information, the last distribution of LLINs to the present study areas was carried out in 2009 on free basis from district health offices to each household. However, assessment on possession and utilization of the LLINs was not done since then in this area. The World Health Organization (WHO) [17] recommends periodic household surveys to assess whether populations at risk receive sufficient LLINs/ITNs, that there is proper use of LLINs/ITNs. The present study was conducted to assess net possession, proper utilization and sufficiency of existing nets for all family members.

Methods

Study settings

This cross sectional comparative study was conducted in two rural settings; one site was near to a man made lake, Gilgel Gibe Hydroelectric Dam (GGHD), and a control site from an area distant from the lake. The site near GGHD is expected to increase the risk of malaria infection due to the man made lake and hence this exposure in turn increases awareness of the residents about malaria risk and its control interventions [18]. The distant site from the artificial lake has not been undergone environmental modification like GGHD and would not be expected to affect the awareness level of the resident regarding malaria control intervention; hence, it is considered to be a control village.

The main socio economic activities of both communities (villages) are mixed farming, including the cultivation of staple crops, and raising of cattle and small stock. All the villages are accessible to primary health care services (a health post for each *kebele*/village and one health centre in common). The villages were selected because of their similarity of geographic features within the Dam area with regard to altitude and presence of rivers, and equivalent range of distance from water bodies as a main risk of malaria.

GGHD is located 260 km southwest of Addis Ababa, the capital of Ethiopia, at 07.4283° to 07.5668° N and 037.1153° to 037.2033° E. The area lies between 1,734 and 1,861 m above sea level, which is within the range of mosquito breeding altitude. Surveys conducted in the area [9,19,20] have shown that the prevalence of malaria in children was higher by many folds than the national malaria indicator survey results of 2007 [14]. The study households were selected from those that live within a 10 km radius of this artificial lake.

The control villages were identified from Ilfeta District, which is located adjacent to the GGHD on the west side. All the control villages are more than 15 km away from the lake so that the possible effect of the dam would not be reflected in the control area. This study considered household as a unit of study. The respondents to the survey were heads/spouses of households from the sample clusters (*gots*) consisting of about 30 households each.

Sample size determination and sampling technique

The number of households used for study was calculated using two population proportion formulae [21,22] taking into account the two study sites (GGHD and control villages). From previous study [9], the proportion of households with at least one LLIN/ITN in GGHD village was 77%; assuming 95% confidence interval and power of 80% to detect a difference of 9% between proportions of LLINs/ITNs owing households in the two sites the sample size was calculated. Considering a 10% contingency for non respondents, the number of households included in the survey was estimated to be 1,186 households from each site which implied a total of 2372 households.

Initially, both villages (GGHD and control villages) were arranged into clusters (*gots*) based on their distances from the GGHD and other water bodies (streams, rivers, ponds, marshy lands) as possible mosquito breeding sites. The total number of clusters was selected based on the

assumption that each cluster (got) consists of 25-30 households according to current administrative structure). The equivalent number of clusters was categorized as near to and distant from water bodies based on maximum mosquito flight range [23]. The study clusters were selected randomly both from those near and distant gots.

Conducting the survey

Household surveys were conducted during malaria peak transmission season in November 2012, on selected households. Semi-structured questionnaires are usually considered best for determining the frequency of beliefs, opinions, views, perceptions, and reported practices pertaining to malaria prevention and control, upon which more valid generalizations are possible [24-27]. Data were collected regarding socio-economic and LLIN possession and utilization. A questionnaire was developed by reviewing relevant literature, such as malaria indicator survey documents [28-31].

Data management and analysis

Data were checked by investigators for correct completion of questionnaires. The edited data were entered into EPI data and exported to SPSS Statistics software version 20 for Windows. Data cleaning, recoding and restructuring of some variables to make them amenable for analysis (data preparation) was carried out using SPSS Statistics software. Durable household assets, sanitation facilities, farm animals, grain produced in the preceding year of the survey, housing conditions and vehicles were considered in the construction of household relative wealth index (RWI) using principal component analysis.

Socio-economic and demographic characteristics of study subjects were summarized in a Table and compared on the basis of means of continuous variables such as age, family size and income, using *t* test for differences of means. Multinomial logistic regression was used to analyse factors associated with possession of LLINs and the number of LLINs owned. Factors affecting utilization of LLINs were analysed using binary logistic regression. To ensure the data quality, the data collection questionnaire was pretested, checklists and field guidelines were used. Adequate training was given to data collectors and field supervisors and job supervision was carried out daily by field supervisors.

Ethical considerations

Ethical clearances were obtained from the Addis Ababa University College of Health Sciences Ethical Review Board and Oromia Regional Health Bureau. Cooperation and community consent was requested by formal letter and obtained from Jimma Zonal Office, District Health offices and local administrators; verbal consent was obtained from study subjects. Individuals who complained of fever were treated based on Ethiopian Malaria Diagnosis and Treatment Guideline [1]. Individual information was kept confidential: the names of individuals were removed from completed questionnaires and identified only by number; hard copies of the information were kept in a locked cupboard and the results were summarized in an aggregated manner.

Results

A total of 2,373 (100%) individuals responded to the survey; 1,187 (50%) were from GG and 1,186 (50%) were from the control villages, corresponding to the number of households 5,916 (49.8%) and 5,981 (50.2%) respectively, and had similar sex compositions. The majority of heads of household in both sites were married although the figure was higher in control village (88.8 vs 86.5%); close to 9% of household heads from both study areas reported that they were widowed and about 1% of them were divorced. About three quarters of heads of households, 77.4% GG and 73.4% control, were illiterate. Those that attended elementary (grades 1-8) constituted 11.5% from GG and 17.2% from control areas. Below 3% of heads of households attended grade 9 or more in both study sites. With regard to occupational status, most were farmers: 89.2% from control villages exceeded that of GG (66.3%) by about a quarter. Accessibility to health services in terms of distance, all of the control population reported to be within an estimated distance of 2 km of health services, in contrast to the GG population of which 19.2% reported living more than 2 km from health services. There was a similarity with regard to accessibility to vehicle transportation: about two thirds (60.1% of GG and 62.2% of control) of the study populations were inaccessible to all weather roads to reach health services.

The average age of household members was about 21 years, for both populations. Significant differences were not seen between the two populations regarding household size, average age of the populations, perceived monthly expenditure, number of farm animals owned, and amount of grain produced in one year preceding the survey. However, differences were observed pertaining to age of household heads where that of GG was higher by about two years, and perceived monthly income and relative wealth index. In both cases the control population seemed better off (Table 1).

The overall LLIN ownership among the study populations was 56.6% (66.3% of GG, 46.8% of control) whereas 43.4% (33.7% of GG, 53.2% of control) reported that they did not own a net. A higher proportion of GG households reported having at least one LLIN compared to control village (OR = 2.2, P <0.001). More households reported owning only one LLIN than two or more, in contrast to the control household (OR = 2.1, P <0.001) and close to two thirds of GG households bought their LLINs, whether

Table 1 Comparison of study populations on the basis of demographic and economic characteristics of household, Southwest Ethiopia, November 2012

Parameter	GG area mean (SE)	Control area Mean (SE)	Mean difference (SE)	t statistic	95% CI
Household size	4.95 (0.08)	5.06 (0.08)	.104 (0.09)	1.2	.274, .067
Household heads' age	44.4 (0.4)	42.4 (0.4)	2.1 (0.59)	3.5	0.91, 3.2*
Family members' age	20.96 (0.24)	20.63 (0.22)	0.33 (0.32)	1.03	0.20, 0.96
Monthly income	309.5 (6.5)	431.9 (8.8)	122.3 (10.9)	11.2	143.8, 100.9*
Monthly expenditure	263.6 (5.5)	357.8(7.8)	94.2 (9.4)	10.0	112.6, 75.7
Farm animals owned	6.6 (0.1)	7.06 (0.13)	0.47 (0.2)	2.6	0.83, 0.11
Grain produced (quintal)	3.5 (0.2)	3.8 (0.16)	0.4 (0.2)	1.7	0.81, 0.06
HH relative wealth index	0.13 (0.8)	0.12 (0.8)	0.6 (0.1)	2.3	0. 47, 0.04*

GG: Gilgel-Gibe; SE: standard error of the mean difference; quintal: 100 kg
*Significant at 0.05.

subsidized or not, unlike control households where half obtained their LLINs free (OR = 0.63, P <0.001). The mean number of LLINs owned was 1.6 for GG and 1.8 for control village, with a mean difference of −0.26 (95% CI = −0.34, −0.19; SE = 0.04). Fewer respondents from GG replied that they had perceivably sufficient LLINs for their family members compared to control villages (OR = 0.21, P <0.001); however, fewer of GG residents reported intention of having additional LLINs in the future compared to control villages (OR = 0.61) but the difference was not statistically significant (P = 0.22). The majority (96.7%) of GG households were expecting to receive LLINs for free, whereas three quarters of the control households reported the hope of obtaining free LLINs sufficient for the needs of their family members in the future. Only a small proportion (4.2% of GG, 23.3% of control) had the intention to buy LLINs for their families. The average suggested cost of an LLIN was 17.0 Birr (≈ $0.9) with median 10.0 Birr (lower and upper quartiles 6.0 and 20.0, respectively).

The reported utilization rate of LLINs was higher among control households than GG households. Of those households with at least one LLIN, more respondents from GG reported that at least one of their family members did not use bed net compared to control population (OR = 2.8, P <0.001). Similarly, the control population was twice likely (OR = 0.48, P <0.001) to have slept under a bed net the previous night and more than five times likely (OR = 0.19, P <0.001) to have slept under a bed net in the last month preceding the survey, compared to respondents from GG (Table 2).

Factors associated to number of LLINs owned were assessed using multinomial logistic regression. Variables such as gender, educational status and occupational status of household heads did not show a significant association with ownership of LLINs. On the other hand, variables such as age of household heads, household relative wealth index (RWI), distance to nearest health service and accessibility to transportation (all weather roads) did show a significant association with ownership of LLINs. The chance of having a bed net is positively associated with age of household heads; particularly the probability of having two or more was positively related to age of household heads. Those households with heads aged 60 years or above were nearly twice as likely to have one bed net and more than three fold likely to have two or more, compared to families with head of household less than 30 years old. Families with head of household who were married were twice more likely to have two or more LLINs than those families whose heads were single, widowed or separated. Household relative wealth index did not show chance difference of having one bed net among the households of different wealth index quantile categories. On the other hand, the probability of having two or more bed nets was found to be directly associated with household wealth indices. Those households in the fifth quantile category were 3.3 and 1.7 times more likely to have two or more LLINs compared to those households in the first and second quantile categories, respectively.

Households within 1 km of the nearest health services were 1.2 times more likely to have one LLIN and 1.5 times more likely to have two or more LLINS compared to those households beyond 2 km from health services. Those households found from 1 – 2 km were seven times more likely to have one LLIN and nearly 1.2 times more likely to have two or more LLINS compared to those households beyond 2 km from health services. Similarly, those families who had perceivably accessibility to transportation were 1.5 times more likely to have one LLIN and twice as likely to have two or more LLINs compared to those who did not have access to transportation. Residents of GG were seven times and four times more likely to have one LLIN and two or more LLINs than control residents, respectively. Finally, household size was found to be a predictor of the number of LLINs owned. Households with three or less members were more than three times more likely to have one LLIN but

Table 2 Comparison of ownership and utilization of long lasting, insecticide treated bed nets between Gilgel Gibe and control villages, Southwest Ethiopia, November 2012

Long lasting, insecticide treated bed nets (LLINs)		Gilgel Gibe villages		Control villages		OR (95% CI)
		N	%	N	%	
Ownership of LLINs (at least one)	Yes	787	66.3	555	46.8	2.2 (1.9 2.6)*
	No	400	33.7	631	53.2	
Number of LLINs owned	One	418	35.2	194	16.4	2.1 (1.9 3.8)*
	≥ Two	369	31.1	361	30.4	
Source of LLINs	Free	307	39.0	279	50.3	0.63 (0.51 0.79)*
	Bought	480	61.0	276	49.7	
Used last night (those who had ≥1)	Yes	760	80.1	778	76.1	0.47 (0.39 0.57)*
	No	505	39.9	245	23.9	
Used last month (those who had ≥1)	Yes	759	80.0	910	89.0	0.19 (0.15 0.23)*
	No	506	40.0	113	11.0	
Any one from the family member who did not use LLINs	Yes	454	57.7	182	32.8	2.8 (2.2 3.5)*
	No	333	42.3	373	67.2	
Sufficient LLINs for family members (those who have ≥1)	Yes	329	41.8	415	74.8	0.24 (0.19 0.31)*
	No	458	58.2	140	25.2	
Intention to have LLINs in future (those who do not have)	Yes	841	97.9	762	98.7	0.61 (0.28, 1.3)*
	No	18	2.1	10	1.3	
Mechanism of having LLINs	Bought	35	4.2	178	23.3	1.6 (0.2 13)
	Free	805	95.7	577	75.6	11.2 (1.4 89.5)*

*Significant at 0.05.

1.4 less likely to have two or more LLINs. Households having four to six family members were twice as likely to have one LLIN compared to those households with seven or more family members; however, there was no a significant difference between them having two or more LLINs (Table 3).

Regarding utilization of LLINs, factors such as gender, educational and occupational status of household heads were not related to utilization of LLINs. Age, marital status of household heads, relative wealth index, distance to nearest health service, accessibility to transport, residence and household size were significantly associated with the utilization of LLITS. As age of household heads increased, utilization of LLINs showed steady decline. Households with heads less than 30 years and those with household heads of 30 to 49 years reported to have used LLINs, respectively, more than three times and about twice as likely compared to those households with household heads of 60 years or older. However, a significant difference was not seen between households with household heads age 50 years and above. Household heads who were married reported more than three times the use of LLINs compared to households whose heads were widowed, divorced or separated.

Household relative wealth index was found to be an influential predictor of use of LLINs. Wealthy households reported more use of LLINs. The wealthiest families were more than three times more likely to use LLINs than poor families. The least poor households were 2.5 and 1.7 times more likely to use LLINs compared to middle and less poor families, respectively. Households within 1 km radius of health services were 1.75 times, and those within 1 2 km from health services were 6.7 times more likely to use LLINs. Households in the control villages were twice as likely to use LLINs more than households around GGHD. One last influential predictor is household size, where those households with three or fewer members reported more use of LLINs than households with large families (Table 4).

Discussion

This study has tried to assess possession and utilization of LLINs in households of rural communities. Attempts have been made to identify associated factors that influence the ownership and utilization level in the households, comparing the study sites on the basis of characteristics that can possibly make the difference. The coverage of LLINs was relatively higher among GG residents (66.3% vs 46.8%) than control villages. However, both were below the coverage recommended by WHO [17] for an acceptable level of protection. The ownership level was a similar average figure indicated in World Malaria Report of 2011 (median - 56%) [17] from household survey results.

Table 3 Factors associated to number of owned long lasting, insecticide treated bed nets by household, southwest Ethiopia, November 2012

Variables	Variables categories	Total	Owned ≥ 1 LLINs		Owned 1 LLIN	Owned ≥ 2 LLINs
		No (%)	N (%)	AOR (95% CI)	AOR (95% CI)	AOR (95% CI)
Age of household heads	<30 years	356 (15.0)	165 (46.3)	0.4 (0.3, 0.6)**	0.6 (0.4, 0.9)*	0.3 (0.2, 0.4)**
	30-39 years	710 (29.9)	401 (56.5)	0.7 (0.5, 0.9)**	0.8 (0.6, 1.2)	0.6 (0.4, 0.9)**
	40-49 years	548 (23.1)	306 (55.8)	0.7 (0.5, 0.9)*	0.7 (0.5, 1.0)	0.7 (0.5, 0.98)*
	50-59 years	358 (15.1)	218 (60.9)	0.8 (0.6, 1.2)	0.9 (0.5, 1.3)	0.8 (0.6, 1.1)
	≥ 60 years	401 (16.9)	252 (62.8)	1	1	1
Marital status	Married	2,080 (87.7)	1,186 (57.0)	1.3 (0.9, 1.9)	1.0 (0.8, 1.5)	1.7 (1.1, 2.5)*
	Not married	293 (12.3)	156 (53.2)	1	1	1
Household RWI	Poorest	475 (20.4)	241 (50.7)	0.5 (0.4-0.7)**	0.8 (0.5, 1.1)	0.3 (0.2, 0.5)**
	Poor	461 (19.8)	256 (55.5)	0.7 (0.5, 0.99)*	1.0 (0.7, 1.5)	0.6 (0.4-0.8)**
	Middle	466 (20.0)	275 (59.0)	0.9 (0.7, 1.2)	1.1 (0.8, 1.7)	0.8 (0.6, 1.1)
	Less poor	455 (19.5)	273 (60.0)	0.9 (0.7, 1.2)	1.0 (0.7, 1.5)	0.8 (0.6, 1.1)
	Least poor	472 (20.3)	268 (56.8)	1	1	1
Distance to the nearest health service	<1 km	1,655 (69.7)	1,051 (63.5)	21.9 (14.9, 32.2)**	12.4 (8.0,19.2)**	45.1 (29.8, 82.1)**
	1-2 km	490 (20.6)	244 (49.2)	8.5 (5.7, 12.7)**	7.0 (4.4, 11.0)**	11.8 (6.3, 21.9)**
	>2 km	228 (9.6)	47 (20.6)	1	1	1
Accessible to transport	Yes	918 (38.7)	621 (67.6)	2.1 (1.8, 2.5)**	1.5 (1.3, 1.8)	2.1 (1.6, 2.8)**
	No	1,455 (61.3)	721 (49.6)	1	1	1
Residence	GG area	1,187 (50.0)	787 (66.3)	1.8 (1.5, 2.2)**	7.0 (5.5, 9)**	4.3 (3.4, 5.5)**
	Control area	1,186 (50.0)	555 (46.8)	1	1	1
Household size	≤3 members	638 (26.9)	338 (53.0)	0.99 (0.7, 1.3)	3.4 (2.3, 5.0)**	0.3 (0.2, 0.5)**
	4-6 members	1,122 (47.3)	654 (58.3)	1.1 (0.9, 1.4)	2.1 (1.5, 3.0)**	0.9 (0.7, 1.1)
	≥7 members	613 (25.8)	350 (57.1)	1	1	1

*significant at 0.05 and **significant at 0.001.

The perceived utilization of LLINs among those households who had at least one LLIN was higher among the controls (76.1 vs 60.1%). The overall level of utilization of LLINs was similar to other local findings [12,32] which were below WHO recommendation of 80% utilization. In about 58% of GG and 33% of the control village households, at least one person did not sleep under a bed net and similar proportions of households reported respectively that the existing LLINs were not sufficient for their family members. Most of those households expected free distribution of LLINs and only a small proportion of them had the intention to buy LLINs for their families. The average suggested cost of LLINs was 17.0 Birr (= $0.9) with median 10.0 Birr which is similar to a previous finding where nearly half of study participants suggested 10 Birr or lower and the rest above 10.0 Birr for an ITN [33]. This is far below what others reported both from local [34,35] and some African countries [36-38]. The fact that control households were more ready to buy and reported more utilization than GG households implies that the control households were more aware of the benefits of LLINs.

Households with older heads possessed more LLINs, particularly when the number of LLINs owned was considered, but utilization was higher among younger heads. Household relative wealth index was positively associated both to possession and utilization of LLINs as possibly the wealthiest were able to access information to seek and receive or buy LLINs. This is a similar finding where the household wealth status was positively associated with ownership of LLINs [16]. Household wealth index was not found to be an important predictor of number of LLINs owned as the possession of one LLIN was similar for all and only the first and second quantiles were differently disadvantaged to have two or more LLINs. This finding is in agreement with other studies [39-42] where inequalities were observed in the number of ITNs owned and average number of ITNs possessed in which case the poorest were disadvantaged, but this is in contrast to another study [43] which failed to show a difference among socio economic strata with respect to possession and likelihood of receiving free ITNs. Another study reported neither socio economic nor educational level of mothers was associated with ITN utilization by children [44].

Table 4 Factors associated with long lasting, insecticide treated bed net utilization, southwest Ethiopia, November 2012

Variable	Categories	Used LLINs N (%)	AOR (95% CI)
Age head of household	<30 yrs	149 (69.8)	3.5 (1.6, 7.6)**
	30-39 yrs	461 (69.5)	2.1 (1.3, 3.6)**
	40-49 yrs	403 (69.5)	1.8 (1.1, 3.0)*
	50-59 yrs	253 (64.9)	1.4 (0.8, 2.4)
	≥60 yrs	255 (63.0)	1
Gender of household head	Male	1,313 (68.5)	1.1 (0.9, 1.5)
	Female	207 (62.3)	
Marital status of household head	Married	1,384 (67.9)	3.6 (1.0, 12.4)*
	Not married	133 (64.3)	4.6 (0.6, 30.3)
Educational status of household head	None	1,126 (67.7)	1 (0.5, 2.0)
	Read and write	149 (72.9)	1.2 (0.6, 2.7)
	Elementary (1-4)	128 (80.7)	0.6 (0.3, 1.2)
	Elementary (5-8)	75 (64.7)	0.6 (0.3, 1.5)
	Grade ≥9	40 (76.9)	1
Occupational status of household head	Farmer	893 (69.0)	0.5 (0.2, 1)
	Housewife	319 (84.4)	0.6 (0.3, 1.2)
	Daily labourer	12 (46.2)	0.8 (0.3, 2.4)
	Others[1]	41 (67.2)	1
AWI of household	Very poor	182 (55.8)	0.3 (0.2, 0.6)**
	Poor	255 (63.3)	0.3 (0.2, 0.5)**
	Middle	310 (67.5)	0.4 (0.3, 0.7)**
	Less poor	345 (70.7)	0.6 (0.4, 0.9)
	Least poor	395 (75.7)	1
Distance to health services	<1 km	942 (70.9)	17.5**
	1-2 km	260 (69.1)	6.7**
	2 km	63 (100)	1
Access to transport	Yes	637 (57.2)	0.3 (0.21, 0.33)**
	No	880 (77.8)	1
Residence	Gilgel Gibe villages	742 (80.5)	0.5 (0.3, 0.7)**
	Control villages	778 (76.3)	
Family size	1-3 members	288 (69.4)	1.7 (1.2, 2.3)**
	4-6 members	721 (66.2)	1.1 (0.9, 1.4)
	7 and above	511 (68.5)	1

[1]Others include government employees (1.1%) merchants (0.8%), self employed (0.7%) and students (0.3%).
*significant at 0.05 and **significant at 0.001.

Similarly, those households who were nearer to health services and accessible to transportation were better by far than those distant and inaccessible households both in ownership and utilization of LLINs, especially when the number of owned LLINs was considered, nearness to health services is the most influential factor. The importance of distance to nearest health services or markets (possibly due to transportation accessibility), homestead wealth and residences had been identified by other studies [40,41,45] to account for the variation in utilization of LLINs. Unlike other findings [41,42], factors such as gender, educational, occupational, marital status of household heads and family size did not show significant difference both in possession and utilization of LLINs in this study. However, Nelitah Amponsah [45] reported that the aforementioned variables significantly affect the adoption and utilization of ITNs among children under five years of age.

Conclusion

Disparities have been seen among households both in ownership and utilization. The poorest, distant from health services, inaccessible to vehicle transportation households were found to be the most disadvantaged in possession of LLINs. Important factors that adversely influence utilization of LLINs were household WI, distance to health services, inaccessibility to vehicle transportation, being in the control area, larger family size, household with heads that were not in marriage, and households with older heads.

Therefore the investigators suggest that attention needs to be given to the poor, distant and inaccessible households in the efforts of malaria intervention programmes, such as during free distribution of LLINs. Distribution of LLIN programmes should give due consideration to family size. Well tailored information, education and communication (IEC) is needed to address the problem of non users, especially households with older heads.

Abbreviations

AOR: Adjusted odds ratio; FMOH: Federal Ministry of Health; GG: Gilgel gibe; GGHD: Gilgel gibe hydroelectric dam; IEC: Information, education and communication; ITNs: Insecticide treated bed nets; LLINs: Long lasting insecticide treated bed nets; SPSS: Statistical package for social sciences; WHO: World Health Organization.

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

LDS designed the study, undertook the field study, analysed data and wrote the manuscript. WAD designed the study, revised the manuscript and facilitated administrative issues. AAA designed the study, revised the manuscript and facilitated administrative issues. All authors read and approved the final manuscript.

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Annex - II Household survey questionnaire

District_____Kebele_____Got_____Gare_____ house No_____ Family ID _____Name of head of HH_____ Sex_____ Education level_____ date of visit_____/_____/_____Location: Longitude _____ Latitude _____ Altitude _____

Section 1: Household list (record the responses in the respective columns):

101	102	103	104	105	106
ID	Please tell me names of all household members starting from head of the household.	What is **(name)** relationship to the head of household?*[1]	What is (**name)** Sex? M F	What is **(Name)** age?	What is his/her educational status? *[2]
			1 2		
			1 2		
			1 2		
			1 2		
			1 2		
			1 2		
			1 2		
			1 2		
			1 2		

* [1.] **Relationship to head of household:**

01 = head
02 = wife/husband
03 = son or daughter
04 = son-in-law or daughter-in-law
05 = grandchild
06 = parent
07 = parent-in-law
08 = brother or sister
09 = other relative
10 = adopted/foster/stepchild
11 = not related
98 = don't know

*[2.] **Educational status (if ≥7 yrs only):**

1. Doesn't read & write
2. Read but doesn't write
3. Read & write
4. Grade 1 – 4
5. Grade 5 – 8
6. Grade 9 – 10
7. Grade 1 – 12
8. Attended college

Time interview started ____:___; Name and sig. of data collector _____

Section 2 socio-economic background

Write respondent's: name _____ ID _____

READ: Now, I am going to ask you some questions about items related to socioeconomic conditions

(ask one respondent from the household preferably husband/).

S. No	Questions	Response	code	Skip to
Q. 201	What is your occupation?	1. Farmer 2. Merchant 3. Daily laborer 4. Housewife 5. Student 6. Gov employee 7. Private employee 8. Others (specify)	1. 2. 3. 4. 5. 6. 7. 8.	
Q. 202	What is your religion?	1. Muslim 2. Orthodox Christian 3. Protestant Christian 4. Catholic Christian 5. Others (specify) _____	1. 2. 3. 4. 5.	
Q. 203	What is your marital status? **(applicable to a respondent ≥ 18 years old)**	1. Single 2. Married 3. Divorced 4. Widowed 5. Separated	1. 2. 3. 4.	
Q. 204	What is your ethnicity?	1. Oromo 2. Amhara 3. Gurage 4. Tigre 5. Welaita 6. Kefa 7. Dawro 8. Others (specify)	1. 2. 3. 4. 5. 6. 7. 8.	
Q 205	How many domestic animals does the household have? 5.1. Oxen? 5.2. Other cattle? 5.3. Goats & sheep? 5.4. equines 5.5. Poultry? 5.6. Others?	Total # of animals the HH has is _____ 0 1 2 3 4 5 6 7 8 9 ≥10 0 1 2 3 4 5 6 7 8 9 ≥10 0 1 2 3 4 5 6 7 8 9 ≥10 0 1 2 3 4 5 6 7 8 9 ≥10 0 1 2 3 4 5 6 7 8 9 ≥10 0 1 2 3 4 5 6 7 8 9 ≥10		

Q.2 06	What is an estimated monthly household average expenditure in Birr? Write on the blank space provided.	_____ Birr.		
Q. 207	What is an estimated monthly household average ***income*** in Birr? Write on the blank space provided.	_____ Birr.		
Q. 208	What is estimated amount of grains the household produced this year in quintals? 8.1. Maize? 8.2. Teff? 8.3. Sorghum? 8.4. Wheat? 8.5. Barely? 8.6. Others?	Total _____ 0 1 2 3 4 5 6 7 8 9 ≥10 0 1 2 3 4 5 6 7 8 9 ≥10 0 1 2 3 4 5 6 7 8 9 ≥10 0 1 2 3 4 5 6 7 8 9 ≥10 0 1 2 3 4 5 6 7 8 9 ≥10 0 1 2 3 4 5 6 7 8 9 ≥10		
Q. 209	Does your household have: Electricity? A radio? A television? A telephone/mobile? A refrigerator?	Yes No 1 2 1 2 1 2 1 2 1 2 1 2		
Q. 210	Does any member of your household have: **Multiple answers are possible**.	Yes No Bicycle? 1 2 Motorcycle or "bajaj"? 1 2 Car or truck? 1 2		
Q. 211	What type of fuel does your household mainly use for cooking? **Multiple responses are possible. but do not read options.**	1. Electricity 2. Natural gas 3. Biogas 4. Kerosene 5. Coal/lignite 6. Charcoal 7. Firewood/straw 8. Dung 9. other (specify)	1. 2. 3. 4. 5. 6. 7. 8. 9.	

Q. 212	Main material of the floor? **Record by observing**.	1. Natural floor: Earth/sand..... Dung..... 2. Rudimentary floor: Wood planks..... Palm/bamboo..... 3. Finished floor: Parquet or polished wood..... Ceramic tiles..... Cement..... Carpet..... 4. Other (specify)_____	 1. 2. 3. 4. 5 6. 7. 8. 9	
Q. 213	What is the **main source of drinking water** for members of your household? *DO NOT READ RESPONSES. ONE ANSWER ONLY.*	1. Piped private 2. Public stand point 3. Protected wells/springs 4. unprotected wells/springs 5. river/pond	1. 2. 3. 4. 5.	
Q.214	Does the household have toilet facility? **Record by observing**.	1. Yes 2. No ➔216	1 2	➔216
Q.215	What kind of toilet facilities does your household have? **Record by observing.**	1. Private traditional latrine 2. Shared traditional latrine 3. Flash toilet 4. Other (specify)_____	1 2 3 4	
Q.216	Is there any marsh land/stagnant water within short distance of the house? **Observe & record.**	1. Yes 2. No ➔218	1. 2.	➔218
Q.217	Approximately, at what distance from the house are the marsh/stagnant water found? **Observe & record.**	1. Less than 1 km 2. 1 – 2 km 3. More than 2 km	1. 2. 3.	
Q.218	Is there bush, banana or false banana within 200 m of the house? **Observe & record.**	1. Yes 2. No	1. 2.	

Section 3- Long lasting Insecticide treated bed net (LLIN) utilization

Q. 301	At any time in the past 12 months, has anyone sprayed the interior walls of your dwelling against mosquitoes?	Yes..... No..... Don't know.....	1 2 3	 2➔ 303 3➔ 303
Q. 302	How long was it since the house sprayed?	1. Less than a month 2. 1 – 3 months 3. 4 – 6 months 4. 7- 12 months	1. 2. 3. 4.	
Q. 303	Does your household have any mosquito nets that can be used while sleeping?	Yes..... No.....	1 2	 2 ➔319
Q. 304	How many mosquito nets does your household have? IF 5 OR MORE NETS, RECORD '5'.	Number of nets = _____		
Q. 305	Ask respondent to show you the net(s). **Are they Observed?** ***If more than five nets, use additional Questionnaire(s).***	Yes No Net #1 1 2 Net #2 1 2 Net #3 1 2 Net #4 1 2 Net #5 1 2		
Q. 306	Where did you get the nets? **Record the appropriate number (1-5) for each net.**	Net #1 Net #2 Net #3 Net # 4 Net # 5 _____ _____ _____ _____ _____ 1. Bought from District Health Office. …1 2. Given by District Health Office (HC)--2 3. Bought private shop ----------.-.--.3 4. Private clinic …….... 4 5. other (specify) 5	1 2 3 4 5	
Q. 307	How long ago did your household obtain the mosquito net(s)?	Months Years Don't know Net #1 _____ _____ _____ Net #2 _____ _____ _____ Net #3 _____ _____ _____ Net #4 _____ _____ _____ Net #5 _____ _____ _____		

Q. 308	When you got the net, was it already factory-treated with an insecticide to kill or repel mosquitoes?	Yes (1) No (2) Not sure (3) Net #1 _____ _____ _____ Net #2 _____ _____ _____ Net #3 _____ _____ _____ Net #4 _____ _____ _____ Net #5 _____ _____ _____		
Q. 309	Since you got the mosquito net, was it ever soaked or dipped in a liquid to repel mosquitoes or bugs?	Yes (1) No (2) (3) Not sure Net #1 _____ _____ _____ Net #2 _____ _____ _____ Net #3 _____ _____ _____ Net #4 _____ _____ _____ Net #5		2 ➔311
Q. 310	How long since the net was last soaked or dipped? ***Circle the appropriate number (1-5) for the respective nets.***	< 1 months 1 - 24 months >2 yrs Net #1 1 2 3 Net #2 1 2 3 Net 3 1 2 3 Net #4 1 2 3 Net 5 1 2 3		
Q. 311	Did anyone sleep under this mosquito net last <u>night</u>? **Record the appropriate number (1-5) on the space for the respective nets.**	Yes = 1 No = 2 Not sure = 3 Net #1 _____ _____ _____ Net #2 _____ _____ _____ Net #3 _____ _____ _____ Net #4 _____ _____ _____ Net #5 _____ _____ _____		2 ➔313
Q. 312	Did anyone sleep under this mosquito net in the last <u>month</u>?	Yes (1) No (2) (3) Not sure Net #1 _____ _____ _____ Net #2 _____ _____ _____ Net #3 _____ _____ _____ Net #4 _____ _____ _____ Net #5 _____ _____ _____		2 ➔313
Q. 313	Is there anyone from the member of your household who does not use the net?	1. Yes…….. 2. No……	1. 2.	2 ➔315
Q. 314	What was the reason(s) for not using the nets? **Multiple responses are possible, but don't read the options.**	The net(s) is/are not sufficient for members of the household……. The net(s) is/are not convenient to use... The net(s) does/do not protect from getting malaria……. The net(s) is/are torn & out of use…… S/he sleeps outside to look for animals/farm…… Other (specify) _____	1 2 3 4 5 6	

Q. 315	Is/are the net(s) sufficient for all members of your household?	Yes……..1 No ……. 2	1. 2.	1 ➔318
Q. 316	If your household doesn't have bed net, what was/were the main reason(s)? **More than one response is possible, but don't read the options.**	1. We couldn't afford to buy…… 2. The nets do not protect from mosquito bite, thus we don't need them…….. 3. We don't know advantages of the bed nets …… 4. Others (specify) _____	1 2 3 4	
Q. 317	If your household doesn't have bed nets, do you plan to have them in the near future?	1. Yes 2. No	1. 2.	2 ➔319
Q.318	What mechanism have you planed to own the nets? ***More than responses are possible but don't read the options.***	1. Buying them……. 2. We are waiting the gov't to give us… 3. We are waiting the NGOs to give us… 4. Other (specify) _____	1. 2. 3. 4.	
Q.319	At what cost do you wish to buy the bed nets to be protected from mosquito bite/ malaria?	_____ Birr		

Time interview completed ____:___; Name and sig. of data collector _____

Annex - III Blood sample collection format

District _____Kebele _____Goti _____Gare _____house No_____

Name of head of household_____ ID No _____

ID. No. (line No)	Name	Age	Sex: (M/F)	Blood film results: 1 ------ P. falciparum 2 ----- P. vivax 3 ----- mixed 4 --- negative	Signature of the Lab. Tech.

Annex - IV Health facility level data collection format

District _____ Name of Health Facility _____

Name	Sex	Address (Kebele/Got)	Age	Date of diagnosis (DD/MM/YYYY)	Results*	Diagnosis

* Blood film results:

P. falciparum (Plasmodium falsiparum)

P. vivax (Plasmodium vivax)

P. falciparum +P. vivax (Mixed)

Negative

Annex-V Declaration

I, the under signed, declare that this is my original work, which has never been submitted to this or any other university, and that all the resources and materials used for the thesis have been dully acknowledged.

Name: Lelisa Sena

Signature:_____

Date:_____

Place: School of Public Health Addis Ababa University

This thesis has been submitted with my approval as a university supervisor.

Name: Prof. Ahmed Ali

Signature:_____

Date:_____