Australian National University

OPERATIONAL RESEARCH FOR MALARIA ELIMINATION IN BHUTAN

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A thesis submitted for the degree of Doctor of Philosophy of the Australian National University

THESIS DECLARATION

I hereby declare that the work presented is an accurate account of research performed during the academic program towards the degree of Doctor of Philosophy of the Australian National University. This is a thesis by compilation. My contribution to the manuscripts included in this thesis was not uniform; therefore individual statements are included for each manuscript and these statements have been approved by the co-authors as well as my primary supervisor, Prof Archie CA Clements. All references to ideas and work of other researchers have been specifically acknowledged. I hereby certify that the work embodied in this thesis has not already been accepted in substance for any degree, and is not being currently submitted in candidature for any other degree.

Signed: 

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Date: 16/05/2017

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ABSTRACT

Bhutan is one of the 30 countries with a stated goal of malaria elimination, having a target of elimination in 2016. Malaria is reported in seven southern districts of Bhutan bordering India, with an at-risk population of 160,000. The aims of this study were to assess Bhutan's elimination progress and identify potential challenges to achieving this national goal. The study involved carrying out field surveys, and analyzing secondary data from the Vector-borne Disease Control Program data repositories. Additionally, an operational tool, namely a spatial decision support system (SDSS), was developed and piloted in two districts for planning, monitoring and implementation of long-lasting insecticide net (LLIN) distribution in December 2013 and for focal indoor residual spraying (IRS) in April and May 2014. The utility and acceptability of the SDSS was assessed through in-depth interviews with the national and district malaria program officials, and field workers.

Malaria trends were analyzed from 2006-2014 using secondary data. There was an overall decrease in malaria cases from 1,751 to 21 cases, from 2006 to 2014. By 2013, there was an average of one LLIN for every 1.51 individuals. The Global Fund to Fight AIDS, Tuberculosis and Malaria (GFATM) was the main international donor, accounting for more than 80% of total funds for malaria elimination. A cross-sectional survey on the coverage, use and ownership of LLINs was carried out in Samdrup Jongkhar and Sarpang districts. LLIN coverage was high with more than 99.0% of households owning LLINs, with regular use throughout the year. Asymptomatic malaria infection was assessed using rapid diagnostic tests (RDT) in 380 randomly selected participants in these districts. All of the results were negative for *Plasmodium* parasites. There was high acceptability of the SDSS by public health officials and field workers.

In conclusion, Bhutan seems to be on track to achieve elimination by 2016 given there was a significant reduction in local malaria cases during the study period and confirmation of the study settings being low-transmission areas with no asymptomatic carriers in the community. LLIN coverage was high with regular use throughout the year. However, malaria control measures were mainly donor funded. The SDSS assisted intensified control measures and surveillance, and was well accepted by the national and district officials, and field workers.

The foreseeable challenges that require national attention to maintain malaria-free status after elimination are: importation of malaria, especially from India; continued protection of the population in endemic districts through complete coverage with LLINs and IRS; and exploration of local funding modalities post-elimination in the event of a reduction in international funding. SDSS assisted control activities and surveillance can be expanded to other malaria transmission districts and integrated into the routine surveillance system, to support malaria elimination and post-elimination strategies in Bhutan.

Key words: Bhutan, malaria, operational research, control, elimination, geographic information system

ABBREVIATIONS

ACO	assistant clinical officer
ACT	artemisinin-based combination therapy
API	annual parasite incidence
APMEN	Asia Pacific Malaria Elimination Network
AS	artesunate
A-T	artemether and lumefantrine
BHU	Basic Health Unit
CPO	chief programme officer
CQ	chloroquine
DDT	dichlorodiphenyltrichloroethane
DoPH	Department of Public Health
EDPT	early diagnosis and prompt treatment
G2C	government to citizen
GFATM	Global Fund to Fight AIDS, Tuberculosis and Malaria
GIS	geographic information system
GoI	Government of India
GPS	global positioning system
GR	geographic reconnaissance
HH	household
HIV	human immunodeficiency virus
IRS	indoor residual spraying
ITBN	insecticide-treated bed net
ITN	insecticide-treated net
IVM	integrated vector management

JE	Japanese encephalitis
LLIN	long-lasting insecticidal net
MCH	Mother and Child Health
MoH	Ministry of Health
NMCP	National Malaria Control Programme
NMEP	National Malaria Eradication Programme
Nu	Ngultrum
OR	operational research
PCA	principal component analysis
PCD	passive case detection
PCR	polymerase chain reaction
PDA	personal digital assistant
PQ	primaquine
PRC	People's Republic of China
QGIS	Quantum Geographical Information System
QT	quinine
RACD	reactive case detection
RDT	rapid diagnostic test
RGoB	Royal Government of Bhutan
RWSS	rural water supply schemes
SDSS	spatial decision support system
SEAR	WHO South-East Asia Region
SoP	standard operating procedure
SP	sulphadoxine
TB	tuberculosis
UNDP	United Nations Development Programme

UNICEF	United Nations Children's Emergency Fund
USD	United States dollar
VDCP	Vector-borne Disease Control Program
WHO	World Health Organization

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CHAPTER ONE

INTRODUCTION

1.1 Background

The Kingdom of Bhutan is a small land-locked country in the Eastern Himalayas, approximately 27° 30' 0" N and 90° 30' 0" E. The altitude ranges from 75m on the southern border with India to more than 7000m in the Himalayas. Bhutan borders the People's Republic of China (PRC) to the north and India to the east, south and west. Bhutan covers an area of approximately 38,394 km^2 and the population was 757,042 in 2015 [1]. Bhutan is divided into 20 administrative districts and 205 sub-districts [2].

Modern health care was introduced to Bhutan in the 1960's, with the First Five Year Plan[1]. In 1961, there were only two hospitals and eleven dispensaries in the country [3], three doctors (two Bhutanese and one Scottish Presbyterian missionary), two nurses and 12 medicinal compounders [2]. Bhutan's health system has made significant progress within the last 55 years. In 2015, there were 31 hospitals, and 235 Basic Health Units and Sub-Posts, 251 doctors, 35 clinical officers[2], 1,618 nurses, and 965 allied health workers, including pharmacists, laboratory technologist, physiotherapists and technicians [4].

Bhutan became a signatory to the Alma-Ata Declaration on Primary Health Care in 1978, which affirmed health as a fundamental human right and the attainment of the highest possible level of health as an important social goal. As mandated by the Constitution of the Kingdom of Bhutan, the state provides free health services in both modern and traditional medicines to all citizens [5].

[1] The Five Year Plans of Bhutan are a series of national economic development plans created by the Royal Government of Bhutan since 1961. The First Five Year Plan was implemented from 1961 to 1966.
[2] Clinical officers- health assistant given advanced training on clinical management.

1.2 Milestones in the national malaria programme

Historically, the first malaria survey in Bhutan was conducted in 1962 with the assistance of the Government of India (GoI) [6]. In 1964, the National Malaria Eradication Programme (NMEP) was launched. Control activities were executed through surveillance inspectors with their numbers increasing rapidly to approximately 32 by 1969 [7]. Since 1969, several centres for active case detection were established in the southernmost districts, which generally experienced the highest burdens of malaria. In these areas, surveillance workers collected blood samples from every household and slides were sent to Indian malaria technicians in Sarpang District for testing. These active surveillance activities continued until 1989 [8].

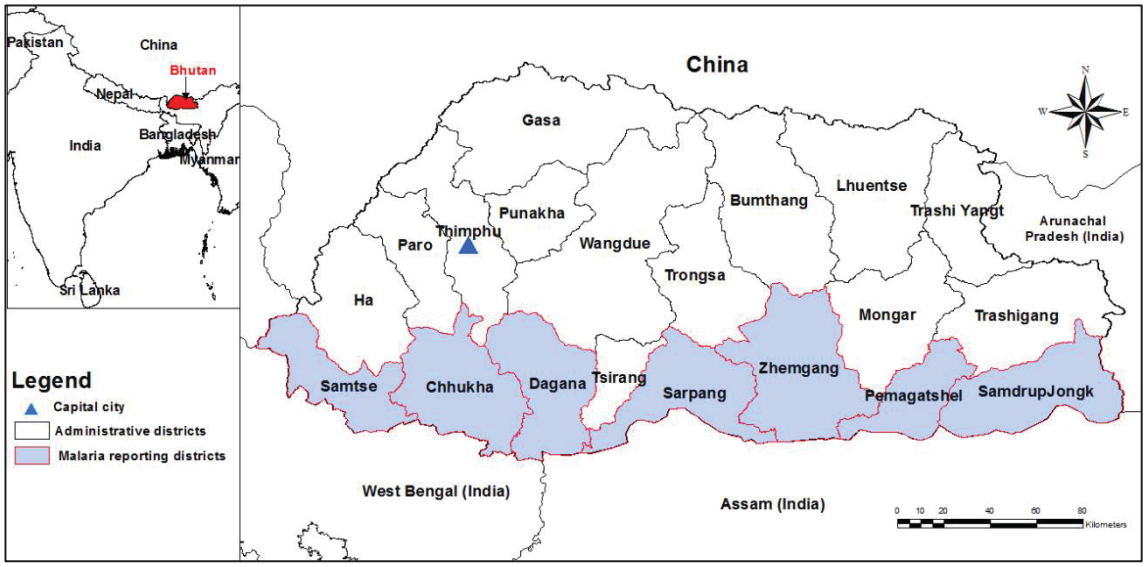

Figure 1 Administrative and malaria endemic districts of Bhutan.

With increasing numbers of malaria cases, Bhutan followed the global paradigm shift from eradication efforts to control. Accordingly, in 1985 the NMEP was renamed the National Malaria Control Programme (NMCP). Additionally, with the signing of the Alma Ata Declaration in 1979, there was an expansion of the primary health care system in Bhutan. Malaria control activities were decentralized and integrated into the primary

health care system. In 2003, NMCP was renamed the Vector-borne Disease Control Programme (VDCP) to incorporate other vector-borne diseases, including dengue, leishmaniasis, Japanese encephalitis and chikungunya.

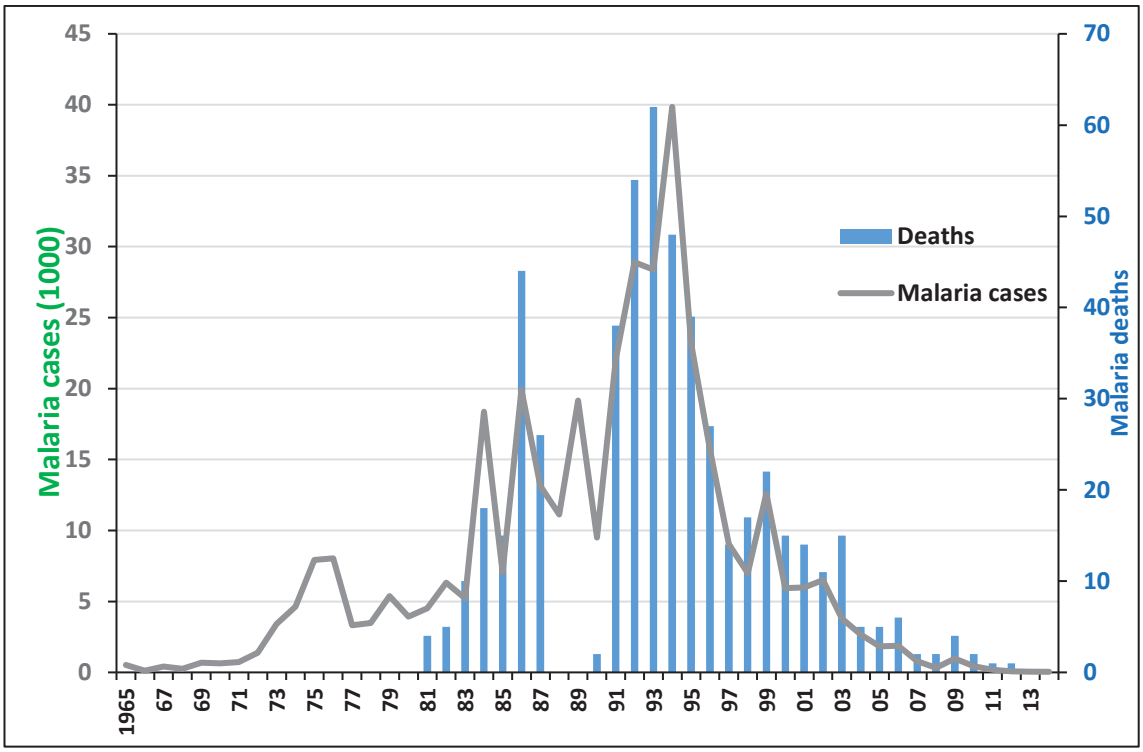

Figure 2 Trends in malaria cases and deaths in Bhutan from 1965-2014. Note: there were no records of deaths from 1965-1980 and 1988-89. (Source: Malaria cases VDCP, Department of Public Health, Ministry of Health, Bhutan)

Malaria is reported from seven endemic districts of Bhutan, namely: Chukha, Dagana, Pemagatshel, Samdrup Jongkhar, Samtse, Sarpang and Zhemgang [6, 9, 11] (Figure 1). Malaria public health services and control activities are decentralized and integrated into the general health care system. Microscopic diagnostic facilities for examination of blood for malaria parasites are available at all district hospitals and second-level Basic Health Units (BHU II)[3] in endemic areas. Rapid diagnostic tests are used when microscopists are not available (out of hours) or during outbreaks or emergencies when the demand for

[3] BHU II- is the lowest level of health facilities in Bhutan.

microscopy is high. To facilitate the smooth functioning of control activities, malaria technicians are stationed in the health centers in the malaria endemic areas. They are aided by insect collectors and sprayers who have been trained by the VDCP, Department of Public Health (DoPH), Ministry of Health (MoH), Bhutan.

The number of malaria cases in 1965 was 518, and increased gradually until 1994 when 39,852 cases and 62 deaths were reported [9]. The trend in numbers of malaria cases then decreased over the years until a resurgence in 2009–2010 with 972 and 436 cases respectively. The number of cases have dwindled since 2010 (Figure 2).

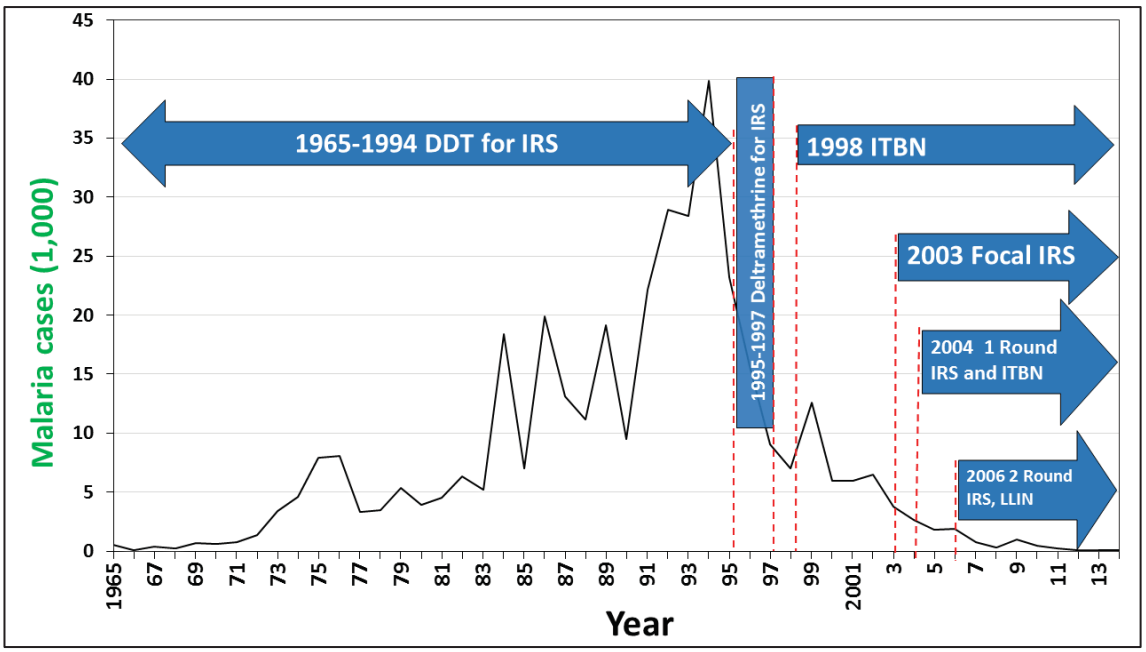

Figure 3 Different types of preventive and control measures in Bhutan. (Source: VDCP, Bhutan) (DDT- dichlorodiphenyltrichloroethane; IRS- indoor residual spraying; ITBN- insecticide treated bed nets; LLIN- long-lasting insecticidal nets)

1.3 Malaria vectors and plasmodium species in Bhutan

In Bhutan, the predominant vectors of malaria are *Anopheles pseudowillmori, An. vagus and An. peditaenistus* [6, 15]. These are endo and exo-phagic and anthropophillic, and abundant during the peak transmission season. *Anopheles minimus* had been the main

vector since the establishment of program until 1989. Of five forms of human malaria, only *Plasmodium falciparum* and *P. vivax* are found in Bhutan.

1.4 Current malaria control activities in Bhutan

Malaria control activities are based on: (1) Early diagnosis and prompt treatment (EDPT) with artemisinin-based combination therapy (ACT), (2) Protection of at-risk populations with IRS and LLINs, and (3) integrated vector management (IVM). EDPT remains a cornerstone of malaria control in Bhutan.

The main control and preventive measure during the eradication era (1964-1971) was indoor residual spraying (IRS) with dichlorodiphenyltrichloroethane (DDT) [9-11]. However, because of reports of resistance to DDT in some areas of the world, global concern over its environmental effects and safety, and reduced public acceptance, DDT was replaced by deltamethrin (a synthetic pyrethroid) from 1995 to 1997. Three rounds of IRS per year, using DDT, was carried out from 1965 to 1974, and two rounds per year from 1974. Active case detection was initiated in 1969 and continued until 1989 [10]. Bhutan aligned its control measures with those advocated by Roll Back Malaria[4] [12, 13] and introduced insecticide-treated bed nets (ITBN) in 1998 [14]. Bed nets were treated with insecticides every six months in districts that reported malaria. Focal IRS during outbreaks and emergencies, and in high *P. falciparum* transmission areas (defined by annual parasite incidence (API) >10%), was introduced in 2003 [6]. Since 2004, annual rounds of IRS and use of ITBN that were treated every six months became the main

[4] Roll Back Malaria is an initiative intended to halve the suffering caused by malaria by 2010. The initiative is being developed as a social movement. Action is directed by national authorities backed by a global partnership which consists of development agencies, banks, private sector groups and researchers. The WHO founded the partnership with the World Bank, United Nations Children's Emergency Fund (UNICEF) and United Nations Development Programme (UNDP) in October 1998.

control and preventive measures. In 2006, the current preventive approach was initiated, using LLINs and two rounds of IRS each year (Figure 3).

Treatment for *P. falciparum* in non-pregnant patients under went many changes. Since 1960s until 1994, *P. falciparum* was treated with chloroquine and primaquine. From 1994 to 1997, the treatment regimen changed to sulphadoxine, quinine and primaquine and then changed again to artusunate, doxycycline and quinine from 1997 to 2006. From 2006, the current ACT treatment regimen was introduced with artemether and lumefantrine (Coartem®) (Figure 4). The use of primaquine 15mg on the third day was introduced in 2013 as a gametocidal drug to prevent the transmission of *P. falciparum*. The treatment for *P. vivax* has remained the same since the establishment of the programme, being chloroquine for three days and primaquine over 14 days [6, 16].

1.5 Knowledge gaps and challenges to malaria elimination in Bhutan

The number of malaria cases have been dwindling in Bhutan in recent years. As a result, Bhutan announced a national strategy to eliminate malaria by 2016 [15]. The focus of the malaria control phase in Bhutan has been on achieving population coverage with preventive methods and access to treatment. However, a move to elimination needs a relentless focus on surveillance and response, and especially on the identification and rapid elimination of foci of all infections, both symptomatic and asymptomatic [17]. The present malaria surveillance system involves passive reporting of fever and malaria cases; it is not designed to detect asymptomatic parasitaemias, which are important contributors to transmission. Asymptomatic infections are common yet difficult to detect, providing persistent parasite reservoirs that impede elimination efforts. Programmes that focus only on vector control and treatment of symptomatic individuals face a significant threat of malaria resurgence.

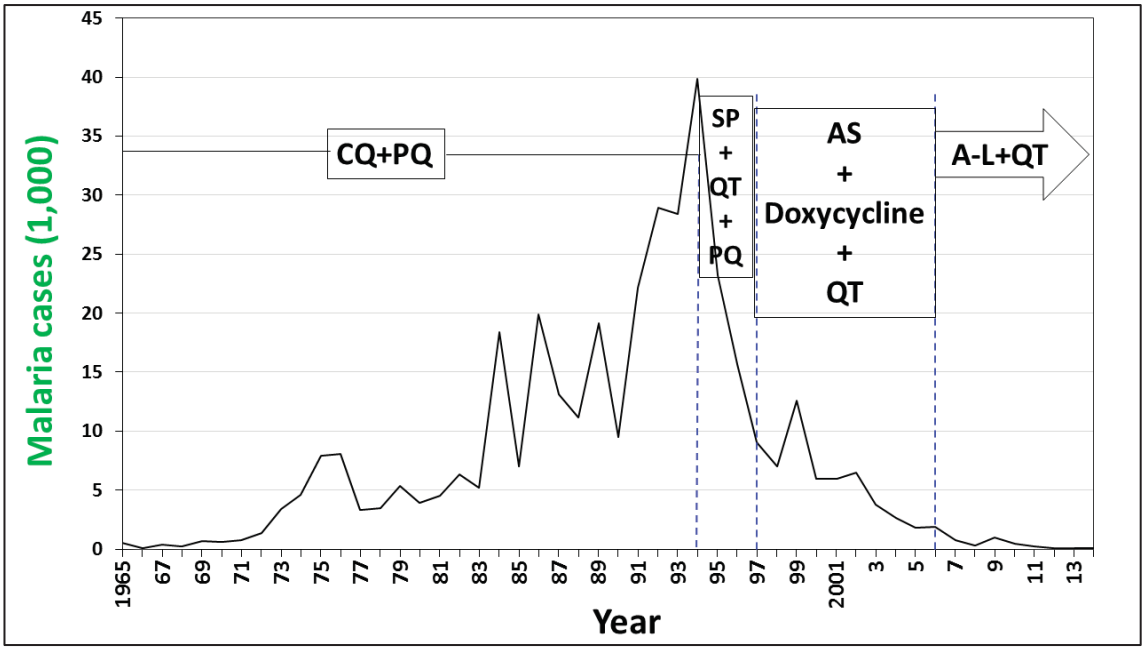

Figure 4 Different treatment regimens of Plasmodium falciparum in Bhutan, 1965-present. (Source: VDCP, Bhutan) (CQ-chloroquine, PQ-primaquine, SP- sulphadoxine, QT- quinine, AS- artusunate, A-T- artemether and lumefantrine)

A primary front-line malaria prevention strategy in Bhutan includes the mass distribution of LLINs in the endemic districts of the country. Between 2006 and 2010, the VDCP under the DoPH of the MoH of Bhutan, distributed over 228,053 LLINs in these districts, supported by grants from the Global Fund to Fight AIDS, Tuberculosis and Malaria (GFATM) [11]. The success of LLINs as a means of eliminating malaria depends on the willingness of the people to use the LLINs regularly. Maintaining coverage and use of LLINs, preventing importation of malaria from India, and the presence of possible reservoirs among people with asymptomatic infections, are the major challenges to malaria elimination in Bhutan.

All the malaria reporting districts in Bhutan share borders with the Indian states of Assam and West Bengal (Figure 1). The international borders are porous, with uncontrolled movement of people across them and communities residing within close proximity to them. A poor health delivery system in Indian states and lack of coordination along the

border districts contribute to cross-border malaria in Bhutan [18, 19]. Additionally, long term migrants from India who work on hydro-projects in Bhutan also contribute significantly to the malaria burden in Bhutan. However, no previous studies have been undertaken to quantify the true burden of imported malaria.

In recent years, Bhutan has been able to achieve universal coverage of LLINs and IRS, and provide other preventive and control measures with the help of international donors including the GFATM, the WHO and Government of India (GoI). The Royal Government of Bhutan (RGoB) has supplemented international funding. As Bhutan plans to achieve elimination, maintaining international funding and political support for malaria control efforts is critical. Increased national funding can be considered as a sustainability factor, especially in countries where malaria cases are declining because these countries are not considered as priority areas any more. In Bhutan and other malaria-eliminating countries, limited information is available on what proportion of control and preventive measure expenditure has been funded by international donors, and how these funds have been utilized.

As with other vector-borne diseases, malaria typically shows temporal and spatial variations that are driven by climatic, ecological and human factors [11, 20-23]. As malaria burden decreases in Bhutan, malaria cases are likely to concentrate spatially in certain geographical locations [11]. Focused interventions in the areas with higher burden of malaria could have greater effect rather than uniform resource allocation [23], but it is currently a challenge to identify these areas with a high degree of accuracy. Currently, the VDCP in Bhutan is unable to address this challenge despite attempts to use geographic information systems (GIS) for intervention planning [14]. Further development and application of GIS-based operational tools such as spatial decision support systems

(SDSS) might help the VDCP in addressing this challenge as Bhutan embarks on malaria elimination [24].

A SDSS is computerized support system that assists with decision making where there is a geographic or spatial component; this is usually housed within a GIS [25]. Data are fed into the SDSS in the field using personal digital assistants (PDAs). A SDSS provides a mechanism to link routinely collected data with the associated spatial information. It can be used to conduct spatial queries and analysis and then produce cartographic maps and reports of the areas of interest. In the context of malaria elimination, these summary statistics of key indicators and maps can be fed back to field teams to enhance implementation of interventions. If designed well, these systems can afford health programs with powerful and user-friendly operational tools for evidence-based decision making to support programmatic management and operational decisions with a spatial or geographical focus. Key elements of a SDSS include: (i) data inputs from a variety of sources (including geospatial data layers); (ii) automated outputs to guide informed and strategic decision making for designated applications; (iii) application/intervention outcomes re-entered back into the SDSS as a cyclical input; and (iv), expert knowledge, integrated throughout all stages of the SDSS process [24]. SDSSs can contain modules for planning, monitoring and evaluating coverage of target populations with interventions, such as IRS and LLINs, and for mapping malaria surveillance data. The ultimate purpose of an SDSS is to improve the efficiency and cost-effectiveness of resource allocation by national malaria elimination programmes, using maps and other outputs.

Operational Research (or Operations Research; OR) in health is defined as: search for knowledge on interventions, strategies, or tools that can enhance the quality, effectiveness, or coverage of programmes in which the research is being done [26] and

results in improved policy-making, better design and implementation of health systems, and more efficient methods of service delivery [27-30]. The goal is to strengthen health services and improve healthcare delivery in disease endemic countries and it has an additional critical role to play in helping solve major implementation problems [26, 31-33]. The key elements of operational research are that the research questions are generated by identifying the constraints and challenges encountered during the implementation of programme activities. So, OR can be imbedded into routine programmatic activities [34]. The GFATM has been encouraging programmes to conduct OR as part of their donor-funded activities [35]. A significant limitation of national programmes has been the ability to manage operational and other data, with there being a general lack of information routinely collected through surveillance and other health information systems [36]. OR can be used to address these knowledge gaps and provide solutions to this limitation.

This thesis will undertake OR studies to determine the preparedness of Bhutan for achieving malaria elimination. Elements investigated will include LLIN coverage and use, prevalence of asymptomatic carriers, malaria trends and burden, and costs analysis of intensified pre-elimination interventions. Potential challenges to elimination efforts and maintaining elimination status will be identified and assessed. Additionally, as an alternative approach to managing operational data in the context of malaria elimination, a SDSS will be developed and piloted in four sub-districts in two malaria endemic districts and evaluated to determine acceptability by end users.

1.6 Research objectives

The research objectives of this thesis are outlined as follows:

1.6.1 To assess malaria trends and burden, and programmatic costs during the intensified control phase in Bhutan;

1.6.2 To identify priorities to achieve elimination and sustain elimination status;

1.6.3 To determine the ownership and use of LLINs by the population in four study sub-districts;

1.6.4 To quantify the prevalence of asymptomatic infection with *P. falciparum* and *P. vivax* in the population of the four sub-districts using RDTs for diagnosis;

1.6.5 To develop and pilot an SDSS as an alternative tool for operational data management in the delivery of LLINs and IRS, and to support reactive case detection (RACD);

1.6.6 To evaluate the SDSS through key informant interviews on the utility and acceptability of the SDSS.

1.7 Approach and methods

The methods are described separately in each research chapter, which are included as published manuscripts. This section summarizes the different methods used throughout the thesis. The study used both quantitative and qualitative research methods to collect and analyze both primary and secondary data.

Primary data were collected through a cross-sectional study to quantify prevalence of asymptomatic carriers and net ownership and use. Additionally, primary data were collected during SDSS field work activities. Field work involved geographic reconnaissance (GR) where geo-coding of households in the study area was undertaken; and training of VDCP officials and field workers (malaria technicians) on the use of the SDSS. Semi-structured in-depth interviews were administered to the officials and malaria

technicians who used the SDSS for intensified malaria control and preventive measures. The interviews covered the acceptability and utility of SDSS.

Secondary data were collected from the VDCP data repository and by way of reviewing published official reports and documents. The data on malaria trends and burden were extracted from the routine surveillance system used in Bhutan. The costs of different control measures and sources of funding were obtained from VDCP financial records.

Ethical approval for different studies was obtained from the University of Queensland Medical Research Ethics Committee, the Research Ethics Board of Health, Ministry of Health, Royal Government of Bhutan, and The Australian National University Human Research Ethics Committee. Verbal permission from local community leaders was sought prior to conducting field work.

Quantitative data analyses were carried out using the statistical packages STATA 12.1 (Stata Corporation, College Station, Texas, USA). The SDSS was built using the open source Quantum GIS software.

1.8 Thesis structure

The thesis is organized into seven chapters. This chapter (Chapter One) contains historical background information on malaria in Bhutan, treatments and preventive measures that were used, research objectives and thesis structure. Chapter Two is a detailed narrative review of the literature that addresses the issue of cross-border malaria. The determinants of cross-border malaria were identified together with possible solutions to the problem were identified. As many countries gear towards malaria elimination, cross-border malaria possess a significant challenge in achieving this aim. Given that Bhutan has a porous and open border with India, cross-border malaria from India poses a significant

challenge to malaria elimination efforts. Chapter Three, another narrative review of the literature, provides a detailed description of the epidemiology of malaria in India, and the potential impact of India's malaria situation on malaria elimination prospects in the region, with special reference to Bhutan's malaria elimination efforts.

Chapter Four presents a descriptive analysis of malaria trends and costs of different control and preventive measures in the pre-elimination phase (2006-2014) in Bhutan. This chapter identified possible challenges Bhutan is likely to encounter post-elimination. Chapter Five describes the findings of a cross-sectional survey on LLIN ownership and use. Additionally, the result of cross-sectional study on the prevalence of asymptomatic cases diagnosed using RDTs is presented. The development and qualitative evaluation of a SDSS for malaria elimination is presented in Chapter Six. Chapter Seven provides a detailed discussion of the findings of the research, presents study limitations, suggests areas for future attention by researchers and presents the conclusions of the thesis.

CHAPTER TWO
CROSS-BORDER MALARIA: A MAJOR OBSTACLE FOR MALARIA ELIMINATION

Numbers of malaria cases have declined in recent years from an estimated 262 million cases globally in 2000 to 214 million cases in 2015. Of 102 malaria endemic countries, 20 countries are pursuing malaria elimination and eight countries are in the phase of preventing reintroduction of malaria. However, cross-border malaria poses significant challenges to these efforts. Areas along international borders are less likely to have optimal control measures in place due to programmatic differences such as divergent use of long-lasting insecticidal nets (LLINs) or indoor residual spraying (IRS) between neighboring countries. Unstable political situations in border areas and a lack of political will of the countries sharing borders to take a coordinated approach, have a detrimental effect in establishing well-functioning health services. Additionally, border areas are places where illegal activities often happen unchecked, such as illegal logging, mining and smuggling. This results in unregulated movement of people and unsafe conditions for public health personnel. Other important but often ignored factors include reduced access to health services, treatment-seeking behavior of marginalized populations who carry malaria parasites across borders, difficulties in deploying prevention programs to hard-to-reach communities and constant movement of people across porous national boundaries. Therefore, unique and complex epidemiological drivers of cross-border malaria warrant specific solutions.

Malaria-reporting districts of Bhutan share borders with the Indian states of Assam and West Bengal. Bhutan's pursuit of malaria elimination is likely to be impaired by the high intensity of malaria transmission in these states. Cross-border malaria is of interest to Bhutan since borders are porous with frequent movement of people between Bhutan and

India. There is looming threat of reintroduction of malaria from India following elimination, should it be achieved in 2016.

This chapter reviews the underlying factors that are associated with malaria transmission across international borders. Some of the possible solutions to address and overcome cross-border malaria are described, including cross-border initiatives such as the Thai-Myanmar and Chinese-Myanmar cross-border malaria control programmes, the Pacific Malaria Initiative, and the Asia Pacific Malaria Elimination Network (APMEN). Overcoming cross-border malaria is of great interest as many countries embark on malaria elimination. This chapter is presented as a paper published in Trends in Parasitology.

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CHAPTER TWO

Cross-Border Malaria: A Major Obstacle for Malaria Elimination

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Contents

Abstract

Movement of malaria across international borders poses a major obstacle to achieving malaria elimination in the 34 countries that have committed to this goal. In border areas, malaria prevalence is often higher than in other areas due to lower access to health services, treatment-seeking behaviour of marginalized populations that typically inhabit border areas, difficulties in deploying prevention programmes to hard-to-reach communities, often in difficult terrain, and constant movement of people across porous

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national boundaries. Malaria elimination in border areas will be challenging and key to addressing the challenges is strengthening of surveillance activities for rapid identification of any importation or reintroduction of malaria. This could involve taking advantage of technological advances, such as spatial decision support systems, which can be deployed to assist programme managers to carry out preventive and reactive measures, and mobile phone technology, which can be used to capture the movement of people in the border areas and likely sources of malaria importation. Additionally, joint collaboration in the prevention and control of cross-border malaria by neighbouring countries, and reinforcement of early diagnosis and prompt treatment are ways forward in addressing the problem of cross-border malaria.

1. INTRODUCTION

Globally, an estimated 3.4 billion people were at risk of malaria in 2012, with populations living in sub-Saharan Africa having the highest risk of acquiring malaria (World Health Organization, 2013). Approximately 80% of cases and 90% of deaths are estimated to occur in the World Health Organization (WHO) African Region, with children under five years of age and pregnant women being most severely affected (World Health Organization, 2012; Casalino et al., 2002; Martens and Hall, 2000; World Health Organization, 2013). WHO estimated that 207 million cases of malaria occurred in 2012 (uncertainty range 135–287 million) and 627,000 deaths (uncertainty range 473,000–789,000) (World Health Organization, 2013). Deaths attributed to malaria have declined by 32% between 2004 and 2010 (Murray et al., 2012). This reduction has most likely been a result of the combined effects of economic development in endemic countries, urbanization and unprecedented financial support for malaria interventions from donors and the associated scaling up of malaria interventions. In sub-Saharan Africa, there was a 66-fold increase in the amount of official development assistance disbursed for malaria control, from $9.8 million in 2002 to $651.7 million in 2008 (Akachi and Atun, 2011). Major funders include Roll Back Malaria, the Global Fund to Fight AIDS, Tuberculosis and Malaria, the US President's Malaria Initiative and the World Bank's International Development Association (Feachem et al., 2010a) and funding from the Bill and Melinda Gates Foundation has been transformational in driving malaria elimination research. The increased funding has supported scaling up of preventive activities such as provision of long-lasting insecticide-treated bed nets (LLINs) and indoor residual spraying (IRS) as the principal vector control measure, as well as improving

timely diagnosis using rapid diagnostic tests (RDTs) and providing effective treatment with artemisinin-based combination therapy (Gueye et al., 2012; Anderson et al., 2011). As a result of these gains, and renewed global interest, 32 of the 99 malaria-endemic countries are now pursuing an elimination strategy, with the remaining 67 aiming to control malaria (Das and Horton, 2010; Feachem et al., 2010a, 2010b).

The second-generation Global Malaria Action Plan (GMAP2) for the period 2016–2025 has now commenced. The GMAP2 aims to accelerate progress in malaria elimination at global, regional and country levels and serve as a major advocacy instrument for the achievement of a malaria-free world. A three-part strategy to eliminate malaria has been developed and is now widely endorsed: (1) aggressive control in highly endemic countries, to lower transmission and mortality in countries that have the highest burden of disease and death; (2) progressive elimination of malaria from the endemic margins, to 'shrink the malaria map' and (3) research into vaccines and improved drugs, diagnostics, insecticides and other interventions, and into delivery methods that reach all at-risk populations (Feachem et al., 2010a; Roll Back Malaria, 2008; Breman and Brandling-Bennett, 2011; Feachem and Sabot, 2008; Mendis et al., 2009). The defining aspects of malaria elimination are outlined in Panel 1.

Although great gains have been made in reducing the overall burden of malaria, impact from elimination and control efforts proves more difficult in areas near international borders. The specific environmental (including physical, social and geopolitical), anthropological, administrative and geographic characteristics of border areas impact uniquely on the epidemiology and control of malaria, resulting in coinage of the terms 'border malaria' and 'cross-border malaria'. Here, we apply the term cross-border malaria to encompass malaria transmission as a result of cross-border movement of people or vectors, in addition to the epidemiological situation that occurs in relation to malaria in areas adjacent or near to international borders (i.e. border malaria).

Cross-border malaria is difficult to manage due to political, economic and geographic constraints (Xu and Liu, 2012). Factors such as frequent movement of humans and vectors across borders, lack of responsibility of individual countries in the border endemic areas and relatively poor access to health care and preventative measures, particularly for mobile populations, leave space for reservoirs of infection that can lead to continued transmission of malaria and vulnerability to malaria outbreaks and epidemics (Gueye et al., 2012).

Panel 1 Malaria elimination defining activities

Malaria elimination requires:

- evidence-based data on the achievement of successful malaria control;
- sufficient evidence that transmission can be interrupted by scaling up planned interventions;
- clearly defined responsibilities for management, including decentralized authority and enforcement of regulatory and disciplinary measures;
- effective systems to ensure coordination between public, private and community-based agencies and services, and to implement cross-border programmes;
- intensive joint inter-sectoral efforts;
- adequate pre- and in-service training of service providers and high-quality supervision/mentoring;
- sustained advocacy, social mobilization, health education and behavioural change communication to support the preparation and implementation of the elimination programme;
- the existence of a monitoring, evaluation and surveillance plan able to timely measure progress, including assessments by independent team(s);
- long-term predictable and sustainable funding available to support planned and unexpected expenses;
- eventually, systems in place for effective vigilance to prevent reintroduction.

WHO. 2007. Malaria elimination- a field manual for low and moderate endemic countries. World Health Organization, Geneva.

The aim of this review is to present a compilation of evidence in the available literature on the impact of cross-border malaria on elimination efforts. Drivers of cross-border malaria are described and measures to prevent or mitigate cross-border malaria are discussed. The review for this paper was carried out using the search engines PubMed, Medline and Google Scholar. The key search words were malaria, cross-border, migration, international borders and malaria elimination. We reviewed all relevant articles written in English.

2. PATTERNS OF MOVEMENT

Cross-border malaria encompasses malaria transmission along international borders as a result of interconnections between human settlements and population movement, including localized border crossings and population migration over larger distances (Guerra et al., 2006; Olson et al., 2010).

Panel 2 Different types of movement across borders

- Circulation encompasses a variety of movements involving no longstanding change in residence.
- Migration involves a permanent change of residence.
- Daily circulation involves leaving the place of residence for up to 24 h.
- Periodic circulation may vary from one night to one year, but is usually shorter than for seasonal circulation.
- Seasonal circulation involves a period in which persons or groups are absent from their permanent homes during a season or seasons of the year.
- Long-term circulation involves an absence from the home for longer than one year.
- Active transmitters 'source' harbour the parasite and transmit the disease when they move to new areas known as 'sinkers', which may have a low-level or sporadic transmission.
- Passive acquirers are exposed to the disease through the movement from one environment to another; they may have a low level of immunity, which increases their risk of clinical malaria.

Border crossings can be defined as movements of local people between countries that occur with or without passing border control checkpoints. Cross-border migration can be defined as the movement of people from a country of origin to a destination country with or without passing border control checkpoints for either short-term or long-term immigration with different channels of migration (Panels 2–5, Koyadun and Bhumiratana, 2005; Bhumiratana et al., 2010).

Population movements can be differentiated by their temporal and spatial dimensions. Temporal dimensions include circulation and migration. Circulation encompasses a variety of movement, usually short-term and cyclical and involving no longstanding change in residence. Migration

Panel 3 Different approaches in tackling cross-border malaria

Joint colourations targeting malaria control and prevention between the countries that share the border.

Robust surveillance system for identifying the importation of malaria across borders and reintroduction of malaria after successful elimination.

Administration of antimalarial drugs with the use of protective measures.

SDSS could be used to target and coordinate cross-border malaria interventions.

Use of mobile technology in assessing the movement of people across borders.

Panel 4 Summary of different interventions to address cross-border malaria

Approaches in tackling cross-border malaria	Advantages	Limitations
Joint collaboration	Prompt sharing of cross-border data. Tackling any possibilities of out breaks.	Requires time to build trust among the health workers of the different countries.
Administration of antimalarial drugs with the use of protective measures for migrants	Avert the risk of spreading and introducing malaria into the naive population. Radical cure of malaria. Prevent development of drug-resistant malaria. The chemoprophylaxis can prevent malaria transmission from sources to sinks.	Ineffective in the mobile population, which involves in crossing border frequently daily. The cost of diagnosis and treatment will be the main barrier if treatment is not provided free.
Surveillance systems	The robust surveillance at points of entry from areas of higher transmission will facilitate swift treatment and follow-up of infected individuals. Once the interruption of transmission has been achieved, surveillance systems will play an important role in the prevention of reintroduction.	The differences in the surveillance system among the countries need to be resolved so that neighbouring countries operate a similar interface. Not easy to identify points of entry in remote border areas.
Spatial decision support system (SDSS)	Conduct high-resolution surveillance and able to locate and classify active transmission foci. A Regional SDSS framework could provide malaria data and malaria transmission across borders. This information could be used by the relevant partners to target and coordinate cross-border malaria interventions.	The technical knowhow would be the main barrier while implementing SDSS. SDSS may not be able to work well among transient/floating population.
Mobile telecommunication on tracking cross-border malaria	Quantify the volume of the people crossing the border areas. Movement patterns derived from phone records can inform on the likely sources and rates of malaria importation.	Use of mobile technology in tracking cross-border malaria is a new concept. Restricted to areas with mobile network coverage; Access to proprietary data will probably be difficult; data quality and completeness potentially low.

Panel 5 Search strategy and selection criteria

The review for this paper was carried out using online search engines including PubMed, Medline and Google Scholar. The key search words were 'malaria', 'cross-border', 'migration of people across international borders' and 'malaria elimination'. We reviewed all the articles written in English with preference for recent publications.

movements involve a permanent change of residence (Prothero, 1977; Stoddard et al., 2009). Circulatory movement can be subdivided into daily, periodic, seasonal and long term. Daily circulation involves leaving a place of residence for up to 24 h. Periodic circulation may vary from one night to one year but is usually of a shorter duration than seasonal circulation. Seasonal circulation involves a period in which persons or groups are absent from their permanent homes during one or more seasons of the year. With regard to long-term circulation, there is absence from the home for longer than one year, but with maintenance of close social and economic ties with the home area (Wolpert, 1965; Martens and Hall, 2000; Roseman, 1971; Stoddard et al., 2009; Prothero, 1977; Pindolia et al., 2012).

People cross international borders for a number of reasons, including migration for work opportunities, visiting friends and relatives (VFRs), tourism, travel for business purposes or cross-border trade, social relations, cultural exchanges (pilgrimages, festivities, fairs, etc.) and displacement as a result of natural and artificial calamities (e.g. wars) and major development projects, such as construction of dams. Some of these movements increase exposure to malaria parasites, particularly in forests or areas of deforestation, where occupational exposure may occur.

It is difficult to obtain basic data on key variables, such as the actual numbers of movements of people across borders, or for such data to be broken down by movement type (e.g. border crossings versus cross-border migrations) (Khamsiriwatchara et al., 2011). For example, migrations across the international borders of Yunnan Province, China, which shares >4000 km of border with Myanmar, Lao People's Democratic Republic (PDR) and Vietnam, take place unchecked (Hu et al., 1998; Clements et al., 2009). Similarly, unmonitored migration of people across the border from Myanmar into Bangladesh jeopardizes the control efforts in Bangladesh (Reid et al., 2010) and imported infections from Yemen into Saudi Arabia continue to challenge Saudi elimination efforts (Alkhalife, 2003).

Movement of people across international borders has contributed to maintaining high transmission at hotspots adjacent to border points (Clements et al., 2009; Carme, 2005). A major challenge to sustaining elimination is addressing the potential reintroduction of cases, either via border areas or from migrant populations (Tatem and Smith, 2010). Nearly 20% of malaria cases treated in Iran in 2006 originated in Pakistan (Reza et al., 2009). Local transmission of malaria in the United Arab Emirates (UAE) came to an end in 1997, and no autochthonous cases were reported from 1998 to 2004. Therefore, the UAE was certified as a malaria-free country. However, there was importation of malaria into the UAE from the neighbouring countries (Sultan et al., 2009).

2.1 Migration for work opportunities

The majority of migrants cross borders in search of better economic, work and social opportunities. Economic migrants are the world's fastest growing group of migrants. Economic motivations are the main reasons for people to migrate from countries with high levels of malaria to malaria-eliminating countries, impeding malaria elimination efforts in those countries (Carme, 2005; Davin and Majidi, 2009; Kitvatanachai et al., 2003; Wangdi et al., 2011). Economic migration is exacerbated when there are substantial differences in the economic development and job opportunities in neighbouring countries. For instance, economic stagnation in Myanmar and rapid economic development in Thailand have stimulated migration from Myanmar to Thailand (Carrara et al., 2013; Delacollette et al., 2009; Huguet and Punpuing, 2005; Khamsiriwatchara et al., 2011; Wangroongsarb et al., 2012), while temporary migration of seasonal workers from Cambodia to Thailand seems to be a key factor responsible for the malaria problem along the Cambodian–Thailand border (Hoyer et al., 2012; Kitvatanachai et al., 2003). It is estimated that 50–70% of all reported malaria cases in Argentina are linked to migration, in particular movement across the border from Bolivia; this migration is fuelled by economic growth on the Argentine side and is not well controlled due to a porous border between the two countries (Gueye et al., 2012). Malaria increased substantially in French Guiana due to the influx of Brazilians to work in gold mining (Carme, 2005). Economic motivations are the main reasons for Afghans to migrate to Pakistan. As high as 64.6% of Afghan migrants crossing into Pakistan cited lack of work in Afghanistan as the main factor leading them to Pakistan (Davin and Majidi, 2009). Economic migration also happens beyond countries sharing common international borders. For instance, imported malaria

in Jiangsu Province, China, from 2001 to 2011 accounted for up to 12.4% of cases, mainly imported by Chinese nationals from African countries as a result of economic migration (Liu et al., 2014).

The resurgence of malaria in Swaziland in early 1970 occurred as a result of the migration of sugar cane workers from malaria-endemic Mozambique (Martens and Hall, 2000; Packard, 1986). More recently, the current migration of labourers into Swaziland from Mozambique is likely to be a challenge for Swaziland's stated plan of malaria elimination by 2015 (Koita et al., 2013). The rapid rise in malaria incidence in Brazil in the late 1970s and early 1980s was attributed to the influx of malaria-infected migrants from endemic Bolivia (Cruz Marques, 1987). The resurgence of malaria in Costa Rica resulted due to the development of the banana industry in which workers were moved from endemic areas into areas with increased suitability for vector breeding (Najera et al., 1998). The oil-exporting countries of the Middle East have attracted a large number of semiskilled workers from malarious countries such as India, Pakistan and Indonesia, who are a source of malaria introduction (Schultz, 1989). The importation of malaria to Kuwait occurs mostly from the Indian subcontinent (Hira et al., 1988, 1985; Iqbal et al., 2003). Saudi Arabia is an attractive employer of skilled workers from malaria-endemic countries such as Iran, Pakistan and India, as well as east Africa (Bruce et al., 2000; Babiker et al., 1998). The main source of malaria cases in the UAE is from Pakistan and neighbouring Oman, including families of UAE nationals living across the border in Oman (Dar et al., 1993). These examples highlight the important role that economic migrations have in re-establishing malaria in areas where control efforts had previously been successful.

2.2 Visiting friends and relatives

Ethnic groups are often spread across borders, and people may cross the international border to meet relatives and friends (Pongvongsa et al., 2012; Noor et al., 2013). Immigrant VFRs frequently return to visit family members whom they had left behind or to introduce new additions to the family of origin. Last-minute travel to visit sick relatives or attend funerals is common, allowing little time for provision and receipt of pretravel advice on malaria prevention. Other travel reasons include finding a spouse, locating missing family, or returning for traditional or cultural ceremonies (Xu and Liu, 1997). Many VFRs stay in family settings in which they may encounter suboptimal housing conditions and increased malaria risk (Bacaner et al., 2004; Scolari et al., 2002; Muentener et al., 1999; Fulford and Keystone,

2005; Di Perri et al., 1994; Barnett et al., 2010; Fenner et al., 2007; Froude et al., 1992; Wagner et al., 2013). VFRs may encounter barriers such as lack of information on services, language, trust of health systems, concerns on their legal status and cost of malaria chemoprophylaxis, which may limit their access to travel clinics (Bacaner et al., 2004; Stager et al., 2009). Migrant VFRs may be exposed to risk of malaria as they visit their families in rural areas with higher malaria transmission rates (Schlagenhauf et al., 2003).

2.3 Treatment-seeking behaviour in border areas

The porous nature of many borders encourages people to migrate and seek treatment across borders. For example, malaria patients from the state of Assam, India, often travel to hospitals in neighbouring Bhutan to receive treatment because treatment is free on the Bhutanese side of the border (Yangzom et al., 2012). Due to poor health infrastructure in Nepal, a large number of people from the plains and hills in the south of the country travelled in the past to hospitals in India to access health care. However, in the last few decades, Nepal has been able to develop health facilities in the country, particularly in the plains, with the establishment of regional, zonal and district hospitals with modern medical facilities. This has resulted in the large-scale reverse flow of people from India seeking treatment in these hospitals (Kansakar, 2001).

Migrant workers are less likely than the general population to get blood tested for malaria parasites and get radical treatment (Hiwat et al., 2012). Migrant workers and border people have often demonstrated suboptimal health-seeking behaviours and often self-medicate. Malaria treatment in the border areas is often inadequate. Inadequate public health facilities in border areas lead local populations to seek treatment from private health professionals, many of whom provide counterfeit or substandard antimalarial drugs, or monotherapies, resulting in an increased risk of antimalarial drug resistance (Pongvongsa et al., 2012; Wijeyaratne et al., 2005). Thus, these groups are among the principal contributors to the emergence of multidrug resistant, which is a particular problem along the Thailand–Myanmar and Thailand–Cambodia borders (Satitvipawee et al., 2012; Thimasarn, 2003; WHO, 2010). Gold miners in French Guiana do not seek malaria treatment in their country due to their illegal status and high local transportation costs; rather, they seek diagnosis and treatment in Suriname. Low accessibility to diagnosis and treatment for these gold miners has resulted in a flourishing black market for antimalarial drugs, often with insufficient quality (Hiwat et al., 2012).

2.4 Displacement due to conflict and major development projects

The World Bank estimates >1.5 billion people live in violent, conflict-affected countries (The World Bank, 2012). Movement of displaced people, including refugees, and soldiers as a result of conflict or war has been implicated as a cause of malaria resurgence in Bangladesh, Vietnam, Sri Lanka, Sudan and Azerbaijan. Decades of internal conflict in Myanmar have resulted in massive population displacement, and >150,000 refuges now live in camps in Thailand (Carrara et al., 2013). Similarly, the Islamic Republic of Iran hosts around 1.5–2 million Afghani refugees (Basseri et al., 2010). These displaced people play an important role in the transmission of malaria due to inadequate control and preventive measures. The displaced people face unreliable access to basic services including health care (Williams et al., 2013). People living in conflict zones, such as the Karen, have higher mortality rates irrespective of malaria incidence (Lee et al., 2006).

The construction of China's Three Gorges Dam resulted in the relocation of 1.3 million people. There has been an epidemic of locally transmitted malaria among residents at the dam site in 1996, and this could recur and spread (Jackson and Sleigh, 2000). The construction of the Bargi dam in India saw a 2.4-fold increase in malaria cases and a more than fourfold increase in annual parasite incidence among children in the villages closer to the dam compared with more distant villages. In addition, there was a strong increase in prevalence in the partially submerged villages (Singh et al., 1999; Singh and Mishra, 2000). Dam construction, irrigation and other development projects, urbanization and deforestation have all resulted in changes in vector population densities and emergence of new diseases and re-emerge old diseases (Walsh et al., 1993; Patz et al., 2000; Gratz, 1999; Keiser et al., 2005).

3. EPIDEMIOLOGICAL DRIVERS OF MALARIA IN BORDER AREAS

Malaria control in border areas is often more difficult than in central and non-border areas due to heavily forested, mountainous and inaccessible terrain, and because of unregulated population movements across the border (Xu and Liu, 2012). In addition, many border areas are inhabited by ethnic minorities (Prothero, 1999; Erhart et al., 2005) with limited formal education (Erhart et al., 2007) and less access to health education efforts. The

impact of different national policies for control and prevention in neighbouring countries is potentially causing a lack of political will to invest in border areas.

3.1 Misalignment of programmatic approaches

Differences in programmatic approaches between neighbouring countries commonly occur making the coordination of control and preventive measures in the border areas challenging. One such example is the Laos–Vietnam border where malaria control on the Laos side is based on distribution of LLINs but on the Vietnamese side it relies mainly on IRS of insecticides (Anh et al., 2005; Hung le et al., 2002). There are also differences in malaria diagnosis and treatment between the two countries. RDTs are mostly used for diagnosis in Laos, while Vietnam uses microscopy as a rule.

Even where the approaches are similar between neighbouring countries, the specific drugs or chemicals used can influence their effectiveness due to parasite or vector resistance. For example, deltrametrin (a synthetic pyrethoid) is used for IRS in Bhutan, whereas dichlorodiphenyltrichloroethane (DDT) is still used in the neighbouring states of Assam, India, even though there are reports of vector resistance to DDT (Dev et al., 2006; Wangdi et al., 2010; Mittal et al., 2004). Effective control or elimination requires both countries across the international boundary to be committed to malaria interventions. In addition, control and preventive activities including IRS need to be synchronized to achieve maximum benefit.

3.2 Forests and deforestation

Both the presence of forests and occurrence of deforestation have impact on increasing malaria risks and transmission in border areas. Populations in border areas are at a greater risk of malaria infections because they frequently visit forestlands, forest fringe areas or forested plantations at or near the border (Chaveepojnkamjorn and Pichainarong, 2004). Forest-related activities and factors related to poverty are major drivers of malaria incidence in Viet Nam (Manh et al., 2011; Erhart et al., 2004). Many species of *Anopheles* mosquitoes that transmit malaria are common fauna of natural forests and forested plantations in border areas. Border populations are particularly at a risk of occupational exposure to malaria through working in crop plantations, forestry, mining, development projects and tourism (Pichainarong and Chaveepojnkamjorn, 2004). Occupational exposures affect the age profile of malaria infections, for example, in forest fringe villages, adult rather than childhood infections are more prevalent due to forest-related activities

of workmen, such as logging, bamboo cutting, charcoaling, foraging and overnight stays in the forests (Dysoley et al., 2008). Migration of the population working in the forest and forest fringe can result in spread via carriers to new areas previously not known for malaria transmission (Wisit Chaveepojnkamjorn, 2005). These result in an increase in human infection, not only within the mobile population but also within the fixed population, to which the migrants return periodically.

Changes in land cover associated with economic activities can enhance contact with mosquitoes and thereby increase malaria transmission. Deforestation has occurred in many malaria-endemic areas as a result of colonization and settlement programmes, logging, increased large-scale agricultural activities, mining, the building of hydropower schemes and the collection of wood for fuel. Deforestation activities lead to a host of influences on the distribution and prevalence of vector-borne diseases. New habitats for *Anopheles darlingi* mosquitoes are created through the formation of large ponds and presence of leaf litter, algae and emergent grasses due to deforestation or activities associated with it. This has led to malaria epidemics in South America (Olson et al., 2010; Vittor et al., 2006, 2009). Increased deforestation in Brazil leads to increased malaria cases in Mancio Lima County (Olson et al., 2010). Populations residing within or near the fragmented forests are at a higher risk of malaria because of increased contact with the vectors at the forest edges and reduced biodiversity. Continued deforestation throughout the world will likely continue to result in increased vector-borne diseases (Guerra et al., 2006).

3.3 Socioeconomic factors

Residual transmission in some malaria-eliminating countries is concentrated in a few hard-to-reach populations, of which mobile populations within border areas are included. These populations often have unofficial status and few economic resources, and can be difficult to locate for the purposes of control and effective treatment of malaria (Stern, 1998).

Ethnic minorities in border areas often have limited formal education, impeding health promotion efforts, resulting in prevalent risk behaviours such as improper use of insecticide-treated nets and other protective measures, and limiting access to healthcare (Prothero, 1999; Erhart et al., 2005). Such groups are typically impoverished and mobile, often driven to more remote areas by marginalization and safety concerns (Martens and Hall, 2000; Chuquiyauri et al., 2012; Prothero, 1995; Xu and Liu, 1997). They might avoid accessing the health systems because of fear of unwanted

attention from government authorities, thus making monitoring and treatment of their malaria difficult (Hiwat et al., 2012). Distinctive ethnic minority groups can vary in terms of cultural practices, languages and life styles that are of relevance to malaria risk, including the practice of staying in the forest overnight.

Poverty serves as a motivating reason for people to seek income from occupational activities associated with forests and mining that might expose them to higher risks (Chaveepojnkamjorn and Pichainarong, 2004). Such activities may be illegal, and as a result, their members often face substantial barriers to healthcare access (Hiwat et al., 2012). For the poor, living conditions are associated with inadequate housing and overcrowding, which increase the risk of malaria. Houses are hastily constructed and are often made of locally available materials. Inadequate housing might allow mosquitoes to enter more easily than well-constructed housing with screened windows. The risk of getting malaria has been shown to be greater for inhabitants of the poorest type of house construction (incomplete, mud, or palm walls and palm thatched roofs) compared to houses with complete brick and plaster walls and tiled roofs (Gamage-Mendis et al., 1991; Konradsen et al., 2003; Lindsay et al., 2002).

4. WAY FORWARD

4.1 International collaboration

Malaria control strategies and policies as well as the quality and management of the health care systems and conventions in data collection may differ across national borders, making cross-border collaboration difficult (Pongvongsa et al., 2012). However, the phenomenon of cross-border malaria provides a strong rationale to develop harmonized cross-border programmes in conjunction with national efforts (Delacollette et al., 2009). The philosophy of cross-border or regional collaboration has been well adopted in different regions, and the results have been positive. One example is the Lubombo Spatial Development Initiative (LSDI) between South Africa, Swaziland and Mozambique. The LSDI was made possible as a result of political commitment through the signing of a protocol of understanding by the head of three states, which created a platform for regional cooperation and delivery. The malaria control programme of the LSDI aimed to achieve maximum effectiveness of malaria control in the highest-risk areas of South Africa and Swaziland bordering Mozambique. These efforts resulted in a

drastic decrease in malaria cases in Swaziland and South Africa (Sharp et al., 2007; Maharaj et al., 2012).

Examples of cross-border collaborations for infectious disease surveillance and control, which in most cases are not malaria-specific but which could provide models for malaria, include the Connecting Organizations for Regional Disease Surveillance (CORDS), the Middle East Consortium on Infectious Disease Surveillance (MECIDS), the Mekong Basin Disease Surveillance (MBDS), the Asian Partnership on Emerging Infectious Diseases Research, the East African Integrated Disease Surveillance Network, the South African Centre for Disease Surveillance and the South Eastern European Health Network, which links the ministries of health of Albania, Bosnia and Herzegovina, Bulgaria, Croatia, Macedonia, Moldova, Montenegro, Romania and Serbia (Gresham et al., 2011).

The MBDS project, which commenced in 2006 established 16 sites at major border crossings between six countries with the aim to carry out joint, cross-border disease outbreak investigations and responses. The joint team carried out outbreak investigation of malaria between provincial sites in Laos PDR (Savannkhet) and Vietnam (Quang Tri) in 2006 and contained the outbreak (Phommasack et al., 2013). CORDS was established in 2008 and provides a new tool for meeting this social networking challenge on a global scale by fostering the growth of trust-based partnerships among professionals that transcend not just organizational but also geopolitical boundaries (Gresham et al., 2011). MECIDS was established in 2003 and links public health experts and ministry of health officials from Israel, Jordan and Palestine (Gresham et al., 2011). MECIDS played a pivotal role in detecting *salmonella* and mumps outbreaks and containing the influenza viruses H5N1 and H1N1 (Gresham et al., 2009). The strength of such collaboration is prompt sharing of cross-border data. However, there are a number of impediments for such collaborations, including the time taken to build the trust required before cross-border data can be shared freely (Phommasack et al., 2013).

Other collaborations have moved beyond surveillance and disease containment. The Pacific Malaria Initiative was introduced in Vanuatu and Solomon Islands in 2007 to aid in their control efforts with the ultimate goal of malaria elimination. The Asia Pacific Malaria Elimination Network (APMEN) was established in 2009 and represents 15 countries in the Asian Pacific region. The Country Partners, together with regional partners from the academic, development, nongovernmental and private sectors and global agencies, including the WHO, collaboratively address the unique

challenges of malaria elimination in the region through leadership, advocacy, capacity building, knowledge exchange and building evidence to support more effective, sustained malaria elimination programmes across the region (APMEN, 2014). Similarly, the Elimination Eight Regional Initiative has been established in Southern Africa to support cross-border collaboration and achievement of mutual goals for malaria elimination in that region. Such international initiatives naturally have a key role to play in developing and implementing strategies to mitigate the threat of cross-border malaria, which is inherently a shared problem between interconnected jurisdictions.

4.2 Surveillance-response and cross-border initiatives

The importance of a robust surveillance-response system at points of entry from areas with local malaria transmission, which facilitates swift treatment and follow-up of infected individuals and their environment, has been recognized (Cohen et al., 2009). Oman has been able to reduce imported cases through mass screening of individuals arriving at the airport from East African countries; those who test positive were treated for free and monitored for two weeks. Both Oman and the UAE have provided free treatment to everyone who tests positive, whether they are nationals or foreigners. Testing for malaria at entry points in Mauritius was shown to provide benefits for investment, by maintaining elimination despite large cyclones in 1994 and 2002 that caused costly damage and an increase in the number of travellers arriving from malaria-endemic countries (Tatarsky et al., 2011; Aboobakar et al., 2012). Screening arriving passengers for malaria at the border points and obtaining a detailed travel history have been deployed to assess the impact of human population movement on malaria in Djibouti (Noor et al., 2011). Proactive prevention programmes to screen all prospective immigrants for malaria infection in their home countries, rather than point of entry, significantly reduced the numbers of imported infections in Kuwait (Iqbal et al., 2003). These approaches work well where border crossings are tightly controlled, but they may be of limited value in remote areas where people pass unchecked between countries.

Population-based surveys that measure cases of parasitaemia can be used to identify high-transmission areas, which often have a low clinical burden because of high rates of immunity in the population. These surveys have the potential to assist malaria control programmes in active detection of

transmission hotspots (Clements et al., 2013; Wangdi et al., 2014). However, such surveys become inefficient when malaria incidence is very low because few cases of parasitaemia are identified relative to the sampling effort. Once the interruption of transmission has been achieved in the context of malaria elimination programmes, intensified disease surveillance and swift intervention responses are the basic requirements to prevent the re-establishment of any introduced parasites. In the post-elimination period, the loss of immunity and the high reproductive rate of the malaria parasite in communities where competent vectors are still present could precipitate outbreaks if malaria infections are re-introduced into the population (Greenwood, 2008), emphasising the need for continued surveillance in areas receptive to resurgence.

In some cases, cross-border malaria control, that is, expansion of malaria control programmes from malaria-eliminating countries to neighbouring malaria-controlling countries, might be necessary to create buffering zones to thwart reintroduction of the parasite (Cui et al., 2012). For example, pilot trials of cross-border malaria control at the Thai—Myanmar and Chinese—Myanmar border areas suggest that organized control in these areas is feasible (Richards et al., 2009). Frequent population movements (every three months) across the Thai-Cambodia border and from the border area across Cambodia indicate the need for heightened surveillance for artemisinin resistance outside what has been designated as the containment zone (Khamsiriwatchara et al., 2011). Obviously, such cross-border activities demand coordination of governments between the neighbouring nations. Cross-border dialogue in solving malaria-related issues need to be initiated, and other control and preventive activities such as IRS need to be synchronized to achieve maximum benefits.

Fever surveillance of people who cross border area can be used to identify malaria-associated fever. Offering free treatments would encourage people to avail this service. The GeoSentinel Surveillance in the United States from March 1997 to March 2006 showed that malaria was the most common specific etiologic diagnosis found in 21% of ill returned travellers with fever (Wilson et al., 2007). Kuwait initiated a proactive preventive programme to screen all prospective immigrants for malaria infection in their home countries. As a result, the malaria cases among the immigrants reduced by 52.6% per year (Iqbal et al., 2003). Fever surveillance was mostly used in tourists and travellers from Europe and North America (Wilson et al., 2007; Leder et al., 2004; Journal, 2004). However, it will

not be possible to monitor fever, when border crossing takes place through informal border and forest areas. Additionally, fever surveillance would be of limited value in the people who have clinical immunity since these people will not develop fever even when they are infected with *Plasmodia* parasites.

4.3 Strengthening of preventive measures for cross-border malaria

Early diagnosis and prompt treatment of people infected with malaria in malaria-eliminated countries would serve a very important tool in preventing reintroduction. However, to deliver prompt diagnosis and treatment, the health systems in most border areas need to be strengthened. The need to take adequate chemoprophylaxis for people moving from non-endemic to malaria-endemic countries and vice versa is often ignored due to deficient knowledge on the availability of chemoprophylaxis and for financial reasons. Drugs for chemoprophylaxis need to be made available in the border areas. The benefits of sleeping under LLINs need to be highlighted through education, and LLINs being made available through social marketing, as has been done for refugees from Afghanistan in Pakistan (Rowland and Nosten, 2001). Alternative approaches such as the provision of insecticide-treated hammocks for people frequenting forest areas in border areas (Magris et al., 2007; Thang et al., 2009), deltamethrin-sprayed tarpaulins or tents, and premethrin-treated blankets and top sheets provide more promising options for people overnighting in the forest (Graham et al., 2002; Rowland and Nosten, 2001). These protective measures achieve the goal of reducing exposure to infected vectors for populations who do not live in traditional housing each night, a feature common to people in border areas.

4.4 Technological solutions to support operational decision making and surveillance response

Spatial decision support system (SDSS) provide enhanced support for decision making, and management using data that has spatial or geographical components (Keenan, 2003). SDSS are generally based on a database housed within a geographic information system with an interactive mapping interface. SDSS can contain modules for planning, monitoring and evaluating the delivery and coverage of interventions including IRS and LLIN within target populations, and for mapping malaria surveillance data (Kelly et al., 2013, 2011; Reid et al., 2010; Srivastava et al., 2009; Zhang et al., 2008).

One role of an SDSS in the context of malaria elimination can be to support high-resolution surveillance, by helping locate and classify active transmission foci (which is not limited to administrative boundaries). Such tools have been successfully used in a variety of countries. Creation of a regional (i.e. multi-country) SDSS framework could provide an opportunity to harmonize malaria data and provide a platform for stakeholders to disseminate and visualize malaria transmission across borders. This information could then be used by the relevant partners to target and coordinate cross-border malaria interventions. Additionally, modern geographical reconnaissance approaches and technologies can be used to develop rapid and accurate field-based procedures for the collection, spatial definition and mapping of malaria elimination target populations in border areas (Bharati and Ganguly, 2013; Kelly et al., 2010).

The use of mobile phone data might provide a novel approach to tracking malaria in cross-border areas. Mobile technology, particularly the cellular phone, has not only penetrated the daily lives of people in metropolitan areas and large rural cities/towns but they have also become popular among those living in remote areas. Data on phone calls made and the location of the call can be captured by the nearest mast that each call was routed through. Such recordings can help to construct trajectories of the movements over time and space (malERA Consultative Group on Monitoring, Evaluation, and Surveillance, 2011; Gonzalez et al., 2008). The captured movement of the people across border areas, when coupled with information about the malaria endemicity of the area, could identify likely sources and rates of malaria importation (Tatem et al., 2009).

5. CONCLUSION

Cross-border malaria will continue to be a problem as long as there are differences in the malaria incidence between neighbouring countries. Cross-border malaria is difficult to control due to (1) the huge number of people crossing international boundaries to engage in a wide variety of activities; (2) most crossings of international borders occurring informally through porous borders; (3) populations residing in the border areas comprising ethnic minority groups with limited formal education and few financial resources; (4) hard-to-reach populations that are typically impoverished and mobile, often being driven to more remote areas by marginalization; (5) a paucity of information on cross-border movement of people and (6) inadequate health systems in many border areas.

Cross-border malaria remains one of the main challenges to malaria elimination. In order to achieve successful malaria elimination, novel approaches for malaria control and prevention need to be identified and implemented in border areas. These include joint collaboration in the prevention and of control measures targeting malaria by neighbouring countries, robust surveillance systems that can identify any importation or reintroduction of malaria for prompt treatment and containment, development of a regional (i.e. multi-country) data sharing framework (which could be based on an SDSS) that could be used by the relevant partners to target and coordinate cross-border malaria interventions and alternative personal protective measures focussing on the needs of border populations; and harnessing technological developments such as using mobile telecommunications data to assess likely sources and rates of malaria importation arising from the movement of people across borders.

CONTRIBUTORS

KW and ACAC conceived the idea for the report. KW did the literature review and wrote the review. ACAC provided substantial input in the form of critical reviewing. MLG and GCK contributed by revision of the manuscript. All authors took part in the review, preparation and final approval of the report.

Glossary

Malaria Control: reducing the disease burden to a level at which it is no longer a significant public health problem.

Pre-elimination: monthly slide or RDT positivity rate among febrile patients with suspected malaria is <5% throughout the year or malaria parasite rate of <5% among people of all ages with current fever or a history of fever in the past 24 h in the peak transmission season in a population-based survey.

Malaria Elimination: reducing to zero the incidence of locally acquired infection in a specific geographic area as a result of deliberate efforts, with continued measures in place to prevent establishment of transmission.

Malaria Eradication: permanent reduction to zero of the global incidence of infection caused by *Plasmodia* as a result of deliberate effort, so that intervention measures are no longer needed.

Vigilance: a function of the public health service during the programmes for prevention of reintroduction of transmission, consisting of watchfulness for any occurrence of malaria in an area in which it did not exist or from which it had been eliminated and application of the necessary measures against it.

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CHAPTER THREE
MALARIA ELIMINATION IN INDIA AND REGIONAL IMPLICATIONS

India is the country that contributes the highest annual number of cases of malaria globally outside of Sub-Saharan Africa. Additionally, India reports the third-highest annual number of *P. vivax* cases in the world. India also has one of the largest populations at risk of malaria infection. Malaria transmission in India is very heterogeneous, with different vector species, vector dynamics and prevalence of parasite infections in different regions of the country. There are varying degrees of insecticide and drug resistance between the regions.

India shares a large international border with many countries. These borders are porous with intense mobility of people. Malaria control and preventive measures across these countries are different, with little cross-border coordination with India. Many countries in the region are pursuing malaria elimination. Bhutan is one such country, with a goal of malaria elimination by 2016. Districts of Bhutan that report malaria lie in the foothills of the Himalayas, adjacent to India. The border is porous, with frequent movement of people in both directions, and in places people live in immediate proximity to the border. Cross-border dialogue between the ministries of health does happen, but without much action on the ground. To maintain elimination efforts in Bhutan post 2016, malaria control and prevention in India will play an important role to this end.

This chapter describes the main challenges of malaria control and prevention in India, and the likely impact of successful malaria control in India in enhancing malaria elimination efforts in South Asia. This chapter is presented as a paper published in Lancet Infectious Diseases.

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Malaria elimination in India and regional implications

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The malaria situation in India is complex as a result of diverse socio-environmental conditions. India contributes a substantial burden of malaria outside sub-Saharan Africa, with the third highest *Plasmodium vivax* prevalence in the world. Successful malaria control in India is likely to enhance malaria elimination efforts in the region. Despite modest gains, there are many challenges for malaria elimination in India, including: varied patterns of malaria transmission in different parts of the country demanding area-specific control measures; intense malaria transmission fuelled by favourable climatic and environment factors; varying degrees of insecticide resistance of vectors; antimalarial drug resistance; a weak surveillance system; and poor national coordination of state programmes. Prevention and protection against malaria are low as a result of a weak health-care system, as well as financial and socioeconomic constraints. Additionally, the open borders of India provide a potential route of entry for artesunate-resistant parasites from southeast Asia. This situation calls for urgent dialogue around tackling malaria across borders—between India's states and neighbouring countries—through sharing of information and coordinated control and preventive measures, if we are to achieve the aim of malaria elimination in the region.

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Introduction

Malaria imposes great health and socioeconomic burdens on humanity, with an estimated 3·2 billion people at risk of being infected.[1] In 2015, there were approximately 214 million cases with 438 000 deaths.[1] The Global Technical Strategy for Malaria 2016–30 has a target to eliminate malaria in at least ten countries by 2020, 20 countries by 2025, and 30 countries by 2030.[1] In 2015, it was estimated that most (88%) malaria cases were in the African region as classified by WHO, followed by the southeast Asian region (10%) and the eastern Mediterranean region (2%).[1] In the southeast Asia region, about 1·4 billion people are reported to be at risk of malaria in ten countries.[2]

India is the most populous country affected by malaria in the southeast Asian region, with over 400 million people at risk of infection.[3] Of the malaria deaths in the southeast Asian region, India reported the highest number (561) in 2014.[4] However, there has been much discussion on the likelihood that deaths could be even higher than reported.[5] In the same year, India has reported the highest number of total malaria cases with 1·1 million, accounting for approximately 75% of all cases in the southeast Asian region.[4,6] India has set the goal of malaria elimination by 2030, in line with the Global Technical Strategy for Malaria 2016–30 by WHO and Asia Pacific Leaders Malaria Alliance Malaria Elimination Roadmap for the Asia Pacific region.[7]

In 2014, around 181·3 million of the Indian population lived in high malaria transmission areas (more than one case per 1000 people).[1] 80% of malaria cases reported in the country are confined to areas where 20% of the population resides—in tribal, hilly, hard-to-reach, or inaccessible areas.[6,8] India has the highest number of *Plasmodium vivax*[9] cases globally and it frequently remains established long after *Plasmodium falciparum* has been eliminated.[10,11]

Malaria control measures are inadequate in India. Less than 20% of the at-risk population are protected by bednets and indoor residual spray, among the lowest rates in the southeast Asian region.[12] Investment in malaria control per capita (US$0–1 per person) is also one of the lowest globally,[13] as is antimalarial treatment. Although reductions in incidence have been reported, the reduction is among the smallest of all countries within the region. Surveillance approaches have been reported to be inadequate, and India has the highest suspected, unconfirmed number of malaria cases in the world.[3,5,8]

India shares land borders with several countries aiming for malaria elimination including Bhutan (by 2016), Bangladesh (by 2020), and Nepal (by 2026).[14,15] Sri Lanka, which eliminated malaria in 2012,[16] is separated from India by only a small distance of sea, with frequent air travel occurring between the two countries. India has endorsed the goal of an Asia Pacific region free of malaria by 2030 and is participating in the work of the Asia Pacific Leaders Malaria Alliance.[12] The slow gains made in India are likely to present a challenge to global and regional malaria elimination. In India, *P falciparum* and *Plasmodium vivax* are the predominant malaria parasite species occurring in nearly equal proportions. The distribution of *Plasmodium malariae* is patchy and *Plasmodium ovale* is of rare occurrence.[17–20]

The aim of this Review is to present a compilation of available evidence on the nature of malaria in India and possible implications on the efforts for malaria elimination in the region.

Milestones in the national malaria programme

India reported approximately 75–100 million malaria cases and 0·8–1 million deaths annually during the pre-independence era (before 1947).[21,22] After independence, the National Malaria Control Programme was launched in 1953, focusing on malaria control in highly endemic areas. In line with a global movement towards eradication, the focus was modified in 1958 to a countywide National Malaria Eradication Programme. The National Malaria Eradication Programme achieved an all-time low incidence of 0·1 million cases per year

with no deaths by 1965.[21] However, these gains were not maintained, with resurgence of malaria resulting in 6·47 million cases in 1976,[23] which necessitated launching the Modified Plan of Operation in 1977, with the aim to prevent morbidity and mortality due to malaria.[24] In 1977, a *P falciparum* containment programme was initiated in 28 districts of the northeastern region with the help of the Swedish International Development Agency and WHO to strengthen the Modified Plan of Operation.[25,26] The containment programme was further expanded to 110 districts covering 121 million people resulting in a significant reduction in *P falciparum* by 21% in 1984 compared with 1981. The *P falciparum* containment programme ended in 1990.[25] In 1998, the National Malaria Eradication Programme changed to the National Anti-Malaria Programme with the main strategy of controlling malaria. To promote synergies in prevention and control of different vector-borne diseases including Japanese encephalitis and dengue, the programme was renamed as the National Vector Borne Disease Control Programme in 2003.[21]

After several years of increasing malaria morbidity and mortality, the Government of India sought and received $165 million from the World Bank in 1997 to implement the Enhanced Malaria Control Project in 100 high-risk districts in eight north Indian states. A primary goal of the Enhanced Malaria Control Project was to enable the malaria programme to transition from its unsuccessful eradication strategy to more modern control methods. The widespread use of insecticide residual spraying was curtailed and instead targeted to high-risk areas. The Enhanced Malaria Control Project have put emphasis on full-scale implementation of early diagnosis and prompted treatment of cases at facility and village levels, introduction of insecticide-treated bednets, and alternative vector control methods (including environmental management and use of larvivorous fish). The quality and completeness of malaria surveillance was improved and laboratory diagnostic capacity was expanded.[21] Malaria morbidity decreased by 43% in districts targeted by the Enhanced Malaria Control Project and nationwide by 38% with almost 1 million fewer cases diagnosed in 2004 than in 1997.[27] Three states, Gujarat, Andra Pradesh, and Maharashtra reduced malaria morbidity by 65–70%. At the same time, the population covered by insecticide residual spraying in Enhanced Malaria Control Project districts decreased by almost 50%.[27] Some states have achieved very low incidence of malaria with the potential of embarking on malaria elimination in the near future.[28] From 2005 to 2010, intensified malaria control projects were started in the northeastern region with financial support from the Global Fund to Fight AIDS, Tuberculosis, and Malaria. With the Intensified Malaria Control Projects, malaria control activities were intensified. The Global Fund supports extended through project round 9 for another 5 years (2010–15) to cover all 89 districts of seven northeastern region states.[21,22]

The main strategies being pursued by the National Vector Borne Disease Control Programme are: disease management through early case detection and complete treatment, integrated vector management to reduce the risk of vector-borne transmission, and supportive interventions including communicating behaviour change, capacity building, and monitoring and assessment of programmes.[29,30]

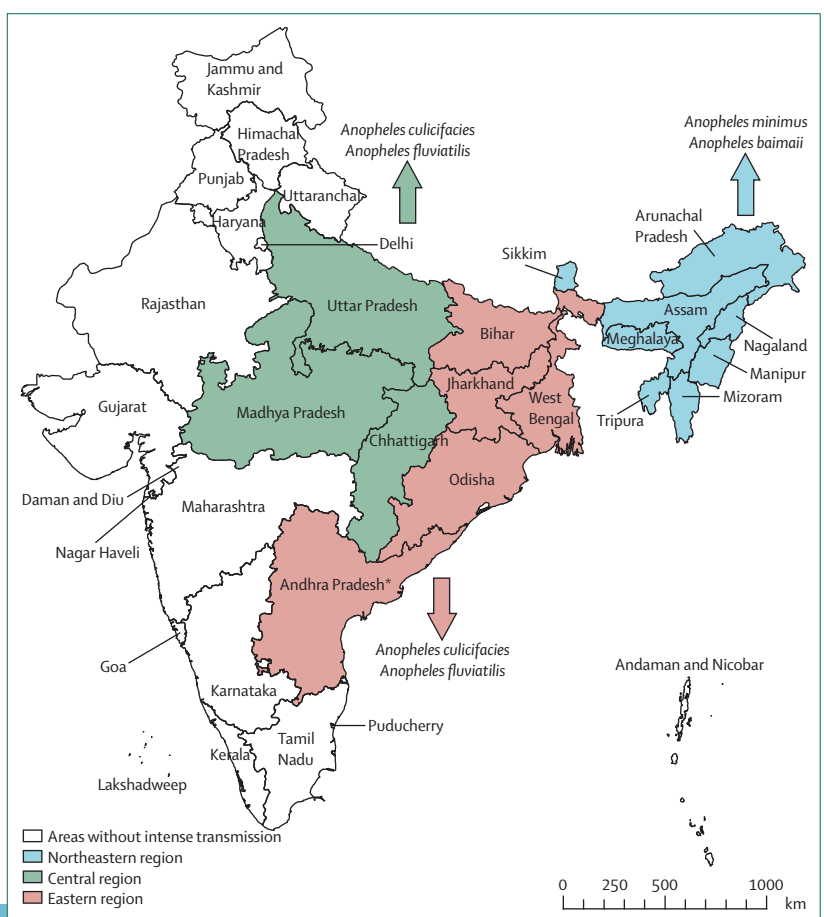

Figure 1: **Main vectors for intense malaria transmission in India by region, correct as of June 1, 2014.**
*Andhra Pradesh is now separated into Telangana and Andhra Pradesh

Status of malaria by region

India is a diverse country with varied environmental settings in different regions. The human reservoirs in both cities and rural areas with frequent movement of people from one part of India to another, mixed with varying degrees of innate and acquired immunity in different communities contribute both to malaria protection and increased susceptibility.[31] There are different vectors that dominate in different areas of India.[32] High malaria transmission regions can be broadly divided into eastern, central, and northeast regions (figure 1). Some states that report high malaria transmission outside these three intense malaria

transmission areas include Gujarat, Rajasthan, and Goa in the west of India.[33]

Eastern region

In 2008, the eastern region had an annual parasite incidence (API) of more than five per 1000 people.[23,31,34] Odisha (formerly known as Orissa) state in the eastern region accounts for a substantial proportion of the malaria burden in India. Jharkhand and Bihar are malaria endemic states that contribute about 12% of the total malaria cases.[35,36] Other states, including West Bengal, also contribute considerably to the malaria burden. This region has hostile terrain, with many remote and under-served areas, along with 40% of the population being below the poverty line and 22% belonging to scheduled tribes (designations given to the most disadvantaged socioeconomic groups in India).[37]

Central region

The main species of malaria causing infections in the central region is *P falciparum*.[38,39] In 2008, the central region had an API of 2–5 per 1000 people.[23,31] Central India is the area most susceptible to malaria as a result of favourable climatic conditions for mosquito propagation and intense vectorial capacity.[40,41] These states were included in the Enhanced Malaria Control Project, funded by the World Bank from 1997. Intense malaria transmission occurs among highly mobile ethnic tribes scattered throughout thinly populated agricultural and forest areas, who have poor access to health infrastructure and increasing exposure to drug resistance among *P falciparum*.[42,43] Malaria epidemics in tribal areas are intense and are not easy to control by routine interventions.[43,44] Efforts are now being made to control malaria by integrating existing tools, such as insecticide residual spraying with synthetic pyrethroid, provision of long-lasting insecticidal nets for high-risk groups, rapid diagnostic tests for on-the-spot diagnosis, and prompt and effective treatment.

Northeast region

The northeast region is made up of the eight states of Assam, Arunachal Pradesh, Meghalaya, Nagaland, Mizoram, Manipur, Sikkim, and Tripura.[9,23,45–48] The population of the northeast region represents 4% of the country, but this region records about 10% of total malaria cases and 20% of malaria-attributable deaths in India.[45] *P falciparum* is the major infection throughout these states.[49] Assam state contributes 50–64% of malaria cases and 75% of *P falciparum* cases in the northeastern region.[50–52]

The main challenges in this region include inadequate financial resources and operational difficulties. Additionally, these areas remain inaccessible owing to floods and poor road infrastructure. Malaria transmission in this region is typical of forest malaria, border malaria, and migration malaria ecotypes.[45,47,49] The northeastern region is marred by ethnic conflicts, has a large itinerant labour force, and is subjected to poor vector control and inadequate surveillance.[53] Additionally, the northeastern region shares a porous border with Myanmar, which has been reported as a major source of antimalarial drug resistance in India.[54,55]

Challenges of malaria elimination in India

Malaria elimination in India faces many challenges (panel). The challenges include resistance of commonly used antimalarial drugs. Different regions of India have different dominant malaria vectors, exhibiting varying habitat and feeding choices. Insecticidal resistance to these vectors has been reported. Urban malaria also poses a substantial malaria burden fuelled as a result of unplanned expansion of cities. A complex health system of public and private providers adds to the socioeconomic and environmental factors to increase the complexities of malaria control and elimination in India.

***Panel 1:* Challenges of malaria elimination in India**

Plasmodium species and drug resistance
- Four *Plasmodium* spp
- Varying degree of drug resistance to *Plasmodium* spp

Vectors of malaria
- Six *Anopheles* spp comprise the main vectors of malaria in India
- Varying degree of insecticide resistance

Urban malaria
- High malaria transmission in cities
- Unplanned expansion of city structures leads to a host of problems including weak health infrastructure, inadequate housing, poor water supply, and overcrowding

Socioeconomic factors
- Rural areas are remote and inaccessible
- Inadequate health system

Health system: national versus state, government versus private
- National programmes are tasked with development of policies
- The state has a pivotal role in delivery of health services
- Malaria patients using private health-care providers often do not report cases to the national programme, leading to an under-reporting of cases

Environmental factors
- Abundant rainfall provides favourable conditions for vector multiplication
- Forested areas have abundant green vegetation that provides a conducive environment for vector multiplication

Porous international borders
- Uncoordinated control measures
- Cross-border malaria
- Drug-resistant *Plasmodium* spp exchange

Antimalarial drug use and resistance

The first report of chloroquine resistance in *P falciparum* was in the northeastern region, specifically in the Karbi Anglong district of the state of Assam in 1973.[56,57] Nowadays, *P falciparum* is resistant to chloroquine throughout India, especially in Odisha, the northeastern region, Madhya Pradesh, West Bengal, and the western states of Rajasthan and Gujarat.[23,54,58–62] There are reports of resistance to chloroquine for *P vivax* in many states particularly western Indian states of Delhi, Rajasthan, Maharashtra, and Gujarat, and the eastern state of Odisha[63–65] but no reports of chloroquine resistance to *P vivax* in other parts of India.[58,66–69]

The effectiveness of the second-line drug combination of sulfadoxine and pyrimethamine in treating *P falciparum* has declined in the areas bordering the India–Myanmar border,[31,54] and failure of this treatment has been reported in West Bengal.[70] However, the drug combination of artemether and piperaquine continues to be highly efficacious for treatment of *P falciparum* malaria.[71]

Delayed clearance of parasites to artesunate, sulfadoxine, and pyrimethamine combination treatment in the northeastern region necessitated a change in the local drug policy in 2013 to permit the use of artemether and lumefantrine combination treatment as the first-line treatment.[22,72] Quinine and mefloquine are still effective to treat multidrug-resistant *P falciparum* malaria in India.[31,45] The only available gametocytocidal drug, primaquine, is effective with no reports of resistance.[66,68]

A major challenge is surveillance for artesunate tolerance or resistance in *P falciparum* parasites. Reduced susceptibility of *P falciparum* to artesunate in southeast Asia poses an imminent threat to India.[73] However, a study from 2015[74] on resistance of *P falciparum* to artesunate was inconclusive. A similar study[75] in West Bengal found treatment failure rates of 9·5% for the combination of artesunate and sulfadoxine, and pyrimethamine combination treatment, which was less than the limit (10%) for drug governmental policy change; treatment failure was shown to be due to sulfadoxine and pyrimethamine combination treatment rather than artesunate. The artemisinin family of drugs are frequently prescribed as monotherapy in the private sector,[76] increasing the risk of drug resistance. The substandard and falsified drugs are a major problem because the private sector works in isolation from the public sector.[77]

Vectors of malaria

Six species from the *Anopheles* genus have been implicated as principal malaria vectors in India.[31,48,78] *Anopheles culicifacies* is the main vector in eastern, central, and northern India[39,43,79–83] and is responsible for 65% of total malaria cases in rural and peri-urban areas.[9,23,84] *Anopheles fluviatilis* is the main vector in the hill and foothill areas of eastern India and central India,[23,31,48,83,85,86] and *Anopheles stephensi* is the main vector in urban India.[9,23,84,87] In the northeastern region, the main vectors include *Anopheles minimus* and *Anopheles baimaii*.[4,9,51,88] *Anopheles sundaicus* is restricted to the Andaman and Nicobar islands. However, *Anopheles annularis* and *Anopheles varuna* act as secondary vectors in India in absence of the previously mentioned primary vectors.[23,89]

These vectors inhabit various conditions; *A stephensi* breeds in clear water,[90,91] *A fluviatilis* breed throughout the year in streams and their tributaries,[17] *A culicifacies* are found in gutters, irrigation tanks, wells, and streams;[92] *A minimus* breeds in slow-flowing seepage water streams with grassy banks;[93,94] and *A baimaii* breeds in pools and rain water collections in forest and forest fringe areas.[95] The different vectors also have different biting habits: *A minimus* bites every month throughout the year, *A fluviatilis* bites in the winter months, and *A culicifacies* and *A baimaii* bite during the wet season.[17,45,88,96–99] *A minimus* feed all through the night with a pronounced peak between 0100 h and 0400 h. Thus variety in vectors creates a situation in which malaria transmission is possible throughout the year and at varying times of day.

Different vectors show varying anthropophagic and zoophilic preferences: *A minimus* and *A baimaii* are attracted to human hosts,[45,100] but *A culicifacies, A annularis, A fluviatilis,* and *A varuna* are predominantly zoophagic.[92,100]

Vector control strategies and challenges

Insecticides applied in India are dichloro-diphenyl-trichloroethane (DDT), malathion 25% water-dispersible powder (WP), synthetic pyrethroids (deltamethrin 2·5% WP, cyfluthrin 10% WP, alphacypermethrin 5% WP, lambdacyhalothrin 10% WP, and bifenthrin 10% WP), hexacyclohexane, and dieldrin.[29,76] Many vectors have developed resistance to DDT because of its mass distribution for insecticide residual spraying during the National Malaria Eradication Programme.[101,102] *A culicifacies* has developed resistance to DDT in many areas.[103–105] Similarly, *A fluviatilis* and *A annularis* are resistant to DDT in some parts of central India, including Maharashtra.[106] However, *A fluviatilis* was still susceptible to DDT in Odisha, eastern India.[107] *A stephensi* is also resistant to DDT,[106,108] whereas *A minimus* has shown reduced sensitivity.[109] By contrast, *A fluviatilis, A minimus,* and *A baimaii* are sensitive to DDT in northeastern regions.[51,110–112] However, the susceptibility of *A sundaicus* to insecticide remains unchanged.[113]

Vectors show varying degrees of resistance to malathion in different parts of India. *A culicifacies* has developed resistance to malathion in 182 districts of India.[103,104] 55% of *A stephensi* were resistant to malathion in south India[114] and up to 80% were resistant in West Bengal.[108] However, no indication of malathion resistance was noted in Maharashtra.[106] *A stephensi* and *A fluviatilis* are reported to be resistant to hexacyclohexane and dieldrin.[108] *A minimus* still appears to be sensitive to deltramethrin.[109] The emergence of resistance to synthetic pyrethroids in *A culicifacies* has been recorded in some parts of India.[115,116]

Vector behaviour presents an additional challenge—for example, some vectors such as *A baimaii*, *A fluviatilis*, and *A minimus* are able to avoid indoor sprayed surfaces because of their exophilic and exophagic characteristics, reducing the effectiveness of insecticide residual spraying.[31,95] A summary of *Plasmodium* species and main vectors in three main regions of India with drug and insecticide resistance is included for comparison (table).

	Central region	Eastern region	Northeastern region
***Plasmodium* species**			
P falciparum	40%	75%	75%
P vivax	60%	25%	25%
Other	<1%	<1%	<1%
Drug resistance status			
Chloroquine*	+	+	+
Chloroquine†	-	+	-
Artesunate*	-	-	-
Sulphadoxine-pyrimethamine*	-	-	+
Quinine*	-	-	-
Primaquine*†	-	-	-
Main vectors			
A culicifacies	+	+	-
A fluviatilis	+	+	-
A minimus	-	-	+
A bambaii	-	-	+
A stephensi	+	+	-
A sandiacus	-	-	-
Insecticide resistance			
DDT	+	+	+
HCH	+	+	+
Malathion	+	+	+
Deltramethrin	+	-	-
Dieldrin	-	+	-

DDT=dichlorodiphenyltrichloroethane. HCH=hexacyclohexane. +=drug resistance. –=no drug resistance. *Resistance to *P falciparum*. †Resistance to *P vivax*.

***Table*: Comparison of different features of *Plasmodium* spp malaria transmission and resistance in three main regions of India**

Urban malaria

Malaria in urban areas was considered to be a marginal problem restricted to mega cities only and not included as part of the National Malaria Eradication Programme in 1958. By the 1970s, incidence of rural malaria dropped drastically to 0·1–0·15 million cases per year, but urban areas reported a rising trend. Around 10–12% of total malaria cases in India were in urban areas at that time.[117]

The Urban Malaria Scheme was approved in 1971 and it had been envisaged that 131 towns in 18 states would be covered under the scheme in a phased manner.[118] At the time of writing, the Urban Malaria Scheme is protecting 130·3 million people from malaria and from other mosquito-borne diseases in 131 towns located in 19 states and union territories.[117] Despite increased control of malaria through the Urban Malaria Scheme in many cities and towns, urban malaria continues to pose a huge burden in India.

Malaria in urban areas is driven by large scale, rural–urban migration triggered by push factors related to insufficient livelihood opportunities in rural areas, and pull factors related to health care and educational opportunities in urban areas. Demographical and societal changes, rising poverty levels, breakdown in municipal rules and regulations (particularly building codes), real estate expansion, and a weak health-care system in surrounding areas also contributed to the urban malaria problem.[118–120] Insufficient capacity of the civic bodies to deal with water supply and sewage and solid waste disposal have led to disruptions of these services, which increases malaria transmission. For example, intermittent water supply has led to increased water storage practices, which has resulted in extensive breeding of *A stephensi*.[117,120,121] Additionally, in an urban setting, insecticide residual spraying is considered to be impractical.[31]

Socioeconomic factors

In rural India, settlements are often remote and difficult to approach, since roads and transport are scarce, and as a result, there are fewer health-care facilities.[122,123] Malaria in rural India is predominantly a disease of the poor. The poor cannot afford private treatment and therefore often resort to self-medication, usually with traditional medicine.[119,124] Education levels in the rural population are low[125] and studies[112,119,126] have shown that delayed seeking of treatment for fever was associated with low educational levels and poor socioeconomic conditions.

Other important socioeconomic and sociocultural factors that play a part in maintaining a high degree of malaria transmission include: human behaviour such as location of hamlets far away from health infrastructure, poor house construction offering easy entry of mosquitoes, sleeping without bednets or in open fields, and outdoor activities after dusk such as hunting or collecting wild foods.[127–129] Poor sanitation (resulting in collection of stagnant water), residing near water, and forests also aggravate the malaria situation in India.[130,131]

Rural areas lack access to proper health services since primary health-care systems are poorly functioning and the private sector remains the backbone of health management.[119] Delayed diagnosis happens because of unavailability or paucity of health facilities in interior villages, hilly areas, and tribal areas. Drug stock shortages often result in late treatment of individuals with malaria. Further clinical referral from the periphery to higher health centres is delayed because of poor road networks in rural areas.[45,132,133] Another challenge that impedes people from seeking early treatment includes reliance on untrained and unlicensed practitioners (called quacks in India),[134] or local healers who promote

worshipping and spirit cleansing, through the offering of special items to spirits or gods to promote healing and often offer hen blood as a sacrifice.[124,125,135–137]

In rural India, control measures such as insecticide residual spraying fail to achieve coverage of target populations as a result of operational constraints including remoteness and isolation of villages and resource limitations.[31] The capacity of the rural communities to buy long-lasting insecticidal nets to protect against the bites of mosquitoes is limited. In some tribal areas, bednets were non-existent and in other areas, despite available bednets, women did not use them regularly because they were not educated on the protection provided by their application.[138] Therefore, the recommendation has been to increase financial access through social marketing, tax exemption, and bulk purchasing.[139]

Local health systems often resort to reactive strategies during malaria outbreaks, in which they offer curative care to large numbers of malaria cases. These strategies result in overcrowding and overstretching of the government health facilities.[44,140]

Health system: national versus state, public versus private

In India, the National Vector Borne Disease Control Programme is a vertically implemented nationwide programme.[141] Health is the responsibility of the state; therefore, malaria control is carried out by the states under the overall guidance of the programme.[76]

The National Vector Borne Disease Control Programme recommends fortnightly national active surveillance for fever, with the assumption that about 10% of the population will have fever at some point in a year. It is assumed that if all or most of the fever cases are diagnostically tested for malaria, an estimate of incidence of malaria can be obtained through the Annual Blood Examination Rate. Without systematic surveillance, reliable epidemiological data are not generated,[142] and deficiencies in the malaria surveillance system result in gross under-reporting.[76,118,143–147]

India has a passive reporting system, and positive diagnoses (by diagnostic assessment) are much more likely to come from people who have symptomatic malaria than would be expected from a random sample of the population. The passive reporting system is unable to detect asymptomatic cases, which is high in areas with intense malaria transmission because of high proportions of clinical immunity,[148,149] often leading to gross under-reporting of malaria incidence.[3,5] Cases processed through the large private sector are often missed, since there is no existing mechanism for data collation from this sector.[51,150] Mortality associated with malaria is also thought to be much higher than what has been reported to WHO.[5] A scarcity of accurate estimates for population at risk is one of the elementary problems in defining intervention strategies against malaria.[151] A substantial proportion of the population harbouring *P falciparum* do not seek treatment and therefore serve as a reservoir for the parasite, maintaining the natural transmission cycle.[152]

Under-reporting of the true burden of malaria in India is a result of poor surveillance,[153] inadequate collaboration between different health providers such as the private health sector and government, and the inability to make accurate estimates of populations at risk. As a result, surveillance data are not useful for effective implementation of control and preventive activities.[23] Other challenges include treatment on the basis of clinical diagnosis rather than microscopic diagnosis, often resulting in underdiagnosis,[154] poor national coordination of state programmes, and insufficient political will, accountability, and governance.

Environmental factors

India is one of the most topographically and climatically diverse countries on earth.[29,48,93,110,155] There is countrywide variation in temperature both by latitude and altitude; the regions around the Himalayas and western Ghats are generally cooler and the coastal areas are tropical and humid. Some locations receive among the highest annual rainfall (>250 cm) in the world, with the highest being Cherrapunjee in the northeastern state of Maghalaya. By contrast, the deserts of Rajasthan receive an average annual rainfall of less than 25 cm.[156] Accordingly, vegetation and mosquito species distributions vary across climatic zones, resulting in widely differing malaria epidemiology. In India, malaria transmission occurs throughout the year,[9,94,157] but transmission is intense during the monsoon from May to October.[150,158] In addition to high temperatures, streams and their tributaries increase humidity, which is conducive for mosquito survival.[132,159]

The central and eastern regions of India are the most vulnerable areas for malaria, on the basis of favourable climatic conditions and intense vectorial capacity to transmit malaria.[40] Man-made environmental and ecological changes such as construction of high-rise and industrial buildings, dams, and deforestation have resulted in malaria changing from forest to plain malaria, and from rural to urban malaria.[160] In northeastern regions, the humidity varies from 60% to 80%, and most of the year is hot and humid (22°C to 33°C) in the foothill ranges of the Himalayas, making the environment in this area particularly conducive for active transmission of malaria.[53,130,161]

Porous international borders

India shares long international borders with China, Bhutan, and Nepal in the north, Myanmar and Bangladesh in the east, and Pakistan in the west.[55] These countries report cases of malaria, with transmission occurring throughout the year. The borders are porous and people move across freely for livelihood and other purposes.[162] Some of the states of India with the highest burden of malaria (annual parasite incidence >20 per 1000 people per year), share borders with Bangladesh and Myanmar.[31] There are village hamlets located adjacent to international

borders where malaria control activities are poorly coordinated.[51] Many of these areas are forested and roads are poorly maintained so officials have little control over provision of health care.[31]

The border with Myanmar is very important since drug-resistant *Plasmodium* spp entered into India for the first time through this border. Artemisinin-resistant *P falciparum* threatens to enter India through Myanmar[55,163] and Bangladesh.[164] Persistent movement of people between India and Bangladesh has led to a continuous exchange of malaria cases between both countries.[109] Effective monitoring systems and cross-border cooperation between Bangladesh and India are essential to reducing the further spread of antimalarial drug resistance.[165,166]

Implication of malaria elimination efforts in the region

Malaria cases have reduced significantly[167] in southeast Asia and many neighbouring countries have embarked on malaria elimination efforts (figure 2). The countries surrounding India attempting malaria elimination are Bangladesh (by 2020), Bhutan (by 2016), and Nepal (by 2026).[15,168] Sri Lanka achieved malaria elimination in 2012.[16] It has been reported that the elimination efforts of Sri Lanka have also been challenged by imported malaria from India.[169] The risk of malaria importation from Tamil Nadu, India, is likely to persist with increasing movement of people between the two nations.[170]

Malaria control efforts in India, particularly Assam and West Bengal, are likely to affect Bhutan's aim of elimination since there are open and porous international borders with free movement of people between the countries.[162,171] Districts of Assam that border Bhutan are among those with some of the highest malaria burdens in the state.[159] Additionally, communities reside within close proximity to the border.[159,172] Malaria among Indian national daily visitors accounted for 730 (13·3% of the total) of the cases recorded in Bhutan from 2006 to 2014.[173] In 2015, malaria among Indian nationals accounted for 70% (71 cases) of all cases in Bhutan.

Malaria hotspots in Nepal in 2012 were noted in the districts bordering Indian states.[168] There is a substantial risk of cross-border malaria with India, with the frequent movement of people across the border[174–176] and import of drug-resistant *Plasmodium* spp and insecticide-resistant vectors from Indian border districts to Nepal threatens Nepal's efforts for malaria elimination.[174]

Some of the districts in Bangladesh with the highest malaria prevalence lie adjacent to Indian states of Assam, Tripura, Meghalaya, and Mizoram.[47,51,109,177] The greatest threat to a successful elimination of malaria in Bangladesh is likely to be impeded because of their porous border with India.[177]

Conclusion

Malaria transmission in India is complex, with varied geopolitical and socioeconomic factors. The climatic and environmental conditions are conducive for development of vectors and transmission of *Plasmodium* spp parasites year round. Vector control has undergone many changes, but some states still embrace DDT as the main insecticide, despite reported resistance. The treatment of malaria has changed to new artemether with lumefantrine combination treatment, since there was evidence of reduced parasite clearance to artesunate, sulfadoxine, and pyrimethamine combination treatment. However, other substantial impediments to effective control measures exist, including inadequate financial support, with key village hamlets located in remote, forested, border areas often inhabited with marginalised ethnic populations. The health infrastructures are underdeveloped with poor malaria reporting systems leading to gross underreporting of the true malaria burden. These challenges in combating malaria are not unique to India and are common to many other countries with few resources that have large, dense populations and porous borders with neighbouring countries. The potential for India to

Figure 2: **Malaria elimination targets for India and neighbouring countries**

Search strategy and selection criteria

We searched PubMed and Cochrane databases with the following keywords in all combinations and without date restrictions until March 30, 2016: "India", "malaria", "drug resistance", "malaria elimination", "*Plasmodium falciparum*", "*Plasmodium vivax*", "insecticide resistance", and "*Anopheles*". We reviewed all the articles written in English. All studies on malaria in India and neighbouring countries from WHO South-East Asia Region in human beings were included. Studies of human malaria from Africa, Americas, Europe, and western Pacific areas and malaria in animals were excluded.

affect elimination efforts in neighbouring countries highlights the importance of international collaborations and coordinated responses. Furthermore, a cross-border malaria strategy with the neighbouring countries is crucial to maintain and achieve the aims of malaria elimination in the region. These strategies could include co-ordinated malaria control activities and development of local cross-border collaborations between states of India and countries that share borders.

Contributors

KW and ACAC conceived the Review. KW undertook the literature search, data extraction, and drafted the report. ACAC assisted in interpretation of results and was involved in the critical revision of the report. CB, MLG, and GCK assisted in drafting and revising the report. VD provided expert opinion and assisted in revision of the report. All authors read and approved the final manuscript.

Declaration of interests

The authors declare no competing interests.

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CHAPTER FOUR

MALARIA BURDEN AND COSTS OF INTENSIFIED CONTROL IN BHUTAN, 2006-14: AN OBSERVATIONAL STUDY AND SITUATION ANALYSIS

The Vector-borne Disease Control Program (VDCP) of Bhutan has made significant gains in reducing numbers of malaria cases in the last 10 years. As a result of these gains, Bhutan is aiming to eliminate malaria by 2016. The reduction in malaria incidence has resulted from adopting new methods of control and prevention such as protection of the at-risk population with long lasting insecticidal nets (LLIN) and instituting two annual rounds of indoor residual spraying (IRS) with pyrethoid. Treatment modalities adopted were the delivery of artemisinin-based combination therapy (ACT) using artemether and lumefantrine (Coartem). These changes have been made possible by generous donations from international donors, including the Global Fund for AIDS, Tuberculosis and Malaria (GFATM), the World Health Organization (WHO) and the Government of India (GoI). This chapter outlines a detailed analysis of the epidemiological situation of malaria in Bhutan, preventive and control measures, and sources of funding during the nine-year pre-elimination period 2006-2015. Efforts were made to identify strengths of the VDCP that would facilitate successful elimination of malaria by 2016. Possible challenges were also identified that are likely to impede the elimination efforts, and threaten achievements in the post-elimination period. These findings will be important to the VDCP of Bhutan in identifying and implementing remedial measures in a timely fashion. This chapter is presented as a paper published in Lancet Global Health.

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Malaria burden and costs of intensified control in Bhutan, 2006–14: an observational study and situation analysis

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Summary

Introduction The number of malaria cases has fallen in Bhutan in the past two decades, and the country has a goal of complete elimination of malaria by 2016. The aims of this study are to ascertain the trends and burden of malaria, the costs of intensified control activities, the main donors of funding for the control activities, and the costs of different preventive measures in the pre-elimination phase (2006–14) in Bhutan.

Methods We undertook a descriptive analysis of malaria surveillance data from 2006 to 2014, using data from the Vector-borne Disease Control Programme (VDCP) run by the Department of Public Health of Bhutan's Ministry of Health. Malaria morbidity and mortality in local Bhutanese people and foreign nationals were analysed. The cost of different control and preventive measures were calculated, and the average numbers of long-lasting insecticidal nests per person were estimated.

Findings A total of 5491 confirmed malaria cases occurred in Bhutan between 2006 and 2014. By 2013, there was an average of one long-lasting insecticidal net for every 1·51 individuals. The cost of procuring long-lasting insecticidal nets accounted for more than 90% of the total cost of prevention measures. The Global Fund to Fight AIDS, Tuberculosis and Malaria was the main international donor, accounting for more than 80% of the total funds.

Interpretation The malaria burden in Bhutan decreased significantly during the study period with high coverage of long-lasting insecticidal nets. The foreseeable challenges that require national attention to maintain a malaria-free status after elimination are importation of malaria, especially from India; continued protection of the population in endemic districts through complete coverage with long-lasting insecticidal nets and indoor residual spraying; and exploration of local funding modalities post-elimination in the event of a reduction in international funding.

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Introduction

Bhutan is one of more than 30 countries with a stated goal of malaria elimination.[1] Bhutan has endorsed the goal of an Asia-Pacific region free of malaria by 2030 and is one of 18 countries pursuing this goal through membership of the Asia-Pacific Malaria Elimination Network.[2] The Vector-borne Disease Control Programme (VDCP), run by the Department of Public Health of Bhutan's Ministry of Health, aims to eliminate malaria by 2016 and obtain WHO certification of elimination by 2020.[3]

Malaria transmission in Bhutan occurs in seven of 20 districts (figure 1). Malaria-endemic districts have a subtropical climate with hot and humid conditions and abundant rainfall during the monsoon period, which lasts up to 3 months.[4] *Plasmodium falciparum* and *P vivax* are the main malaria parasite species in Bhutan and the main vector species are *Anopheles pseudowillmori* and *A culicifacies*.[3,5]

A malaria eradication programme was first established in Bhutan in 1964. However, following a rapid increase in cases, Bhutan transitioned to a malaria control programme from 1971 to 1995. This increase might have been caused by a reduction in the frequency of indoor residual spraying from three times a year during 1965–74 to twice a year from 1974, the coverage of which also fell from 80% in 1973 to below 50% in 1974.[6] Moreover, active case detection was initiated in 1969 and continued until 1989, meaning that a higher proportion of cases was identified, thereby increasing the number of cases recorded.[7] From 1996 to 2003, Bhutan began to reinvest in malaria control activities with goals of improved access to remote and rural areas and difficult-to-reach populations, initiating cross-border prevention and increasing awareness of malaria.[8] In 2004–14, control and preventive measures focused on the scale-up of control and preventive measures in high-risk areas.

The main control and preventive measure during the eradication era (1964–71) was indoor residual spraying with dichlorodiphenyltrichloroethane (DDT); however, because of reports of resistance to DDT in some areas of the world, global concern over its environmental effects and safety, and reduced public acceptance, DDT was replaced by deltamethrin (a synthetic pyrethroid) from 1995 to 1997.[4,9,10] In 1998, insecticide-treated bednets were introduced, as a result of the Roll Back Malaria initiative, which aimed to rely on personal protection sustained by community involvement and participation.[7] In 2003, focal indoor residual spraying was introduced for use

Research in context

Evidence before this study

We searched PubMed for relevant articles using "malaria" AND "Bhutan" as search terms with no specified start date up to Feb 25, 2016, and with no language restrictions. Our search identified 22 studies, of which 14 specifically related to malaria. Two studies described malaria control in Bhutan. Both reports draw attention to importation of malaria across Indian states as a critical issue. One paper outlined Bhutan's plan to screen at border points and major construction sites with expatriate workers, to prevent importation of malaria.

Added value of this study

The study presents a detailed analysis of the trends of malaria in the pre-elimination period in Bhutan with regard to types of infection, age-specific and sex-specific burden, occupation, deaths, and the nationality of patients with malaria. It further analyses the costs associated with malaria elimination, incorporating sources of funding for scale-up of activities leading to pre-elimination. Cost analysis studied individual control and preventive measures including long-lasting insecticidal nets, indoor residual spraying, drugs, and other commodities. Additionally, the ratio of long-lasting insecticidal net coverage per person over three mass distribution periods was presented.

Implications of all the available evidence

The risk of importation of malaria from India necessitates coordinated malaria control activities between India and Bhutan. Additionally, populations in the malaria-endemic districts will need complete coverage with long-lasting insecticidal nets and indoor residual spraying. Local funding modalities post-elimination of malaria need to be explored if a reduction in international funding occurs. Initiation of public–private partnerships in cost sharing and social marketing of long-lasting insecticidal nets is one possible way forward.

during outbreaks and emergencies and in areas of high *P falciparum* transmission with an annual parasite incidence higher than 10 per 1000 population.[11] In 2006, the existing preventive approach was initiated, using long-lasting insecticidal nets and two rounds of indoor residual spraying every year (figure 2).

Malaria control activities are decentralised and integrated into the general health-care system in Bhutan. Microscopic diagnostic facilities for examination of blood for malaria parasites are available to all health facilities in endemic areas. Rapid diagnostic tests are used when microscopists are not available (out of hours) or during outbreaks or emergencies when the demand for microscopy is high. Treatment for *P vivax* malaria has not changed since 1965, and remains chloroquine for 3 days and primaquine over 14 days (figure 2), whereas treatment options for *P falciparum* malaria have changed over the years, and are presently artemether–lumefantrine and quinine (figure 2).

Malaria surveillance in Bhutan is done through passive case detection and fever surveillance, which involves submitting numbers of fever cases at the end of each week to the VDCP from the field through district offices. The latter is an important ongoing surveillance method—an increase of fever cases over the weekly mean of the preceding 5 years triggers an investigation of a possible outbreak of malaria. A spatial decision support system based on geographic information systems (GIS) has been set up to help surveillance in malaria-reporting districts.[7]

This study is a situation observational analysis, defined as an assessment of the present health situation, which is fundamental to designing and updating national policies, strategies, and plans.[12] We aimed to determine the trends and burden of malaria, the costs of intensified control activities, the main donors of the control activities, and the costs of different preventive measures in the pre-elimination phase (2006–14).

Methods

Study design and data collection

We obtained nationwide data about malaria cases in Bhutan from 2006 to 2014 from the national malaria surveillance system, hosted by the VDCP. These data contained laboratory-confirmed malaria cases, which were defined as clinically diagnosed cases with either malaria parasites confirmed by microscopy or a positive rapid diagnostic test result. Since all health services in Bhutan are free of charge with good coverage and no private practices, we can assume that this dataset is complete for clinical malaria cases. Additionally, every health centre in malaria-endemic areas has dedicated malaria technicians who are able to monitor fever cases in their small catchments, thus increasing the likelihood of fever cases being tested for malaria. The infections were categorised by species: *P falciparum* and *P vivax* or mixed infections. The following patient information was extracted for each case: whether the patient was a Bhutanese citizen or a foreign national (foreign nationals were classified as non-Bhutanese citizens visiting or residing in Bhutan), age, occupation, and sex.

Historical information was obtained through searches of databases such as PubMed, MEDLINE, and Google Scholar, using the search terms "Bhutan", "malaria elimination", "long-lasting insecticidal nets", and "indoor residual spraying" between Feb 1, 2015, and March 30, 2016. Search was not restricted to published studies, but included conference presentations, abstracts, and government reports. No language restrictions were imposed.

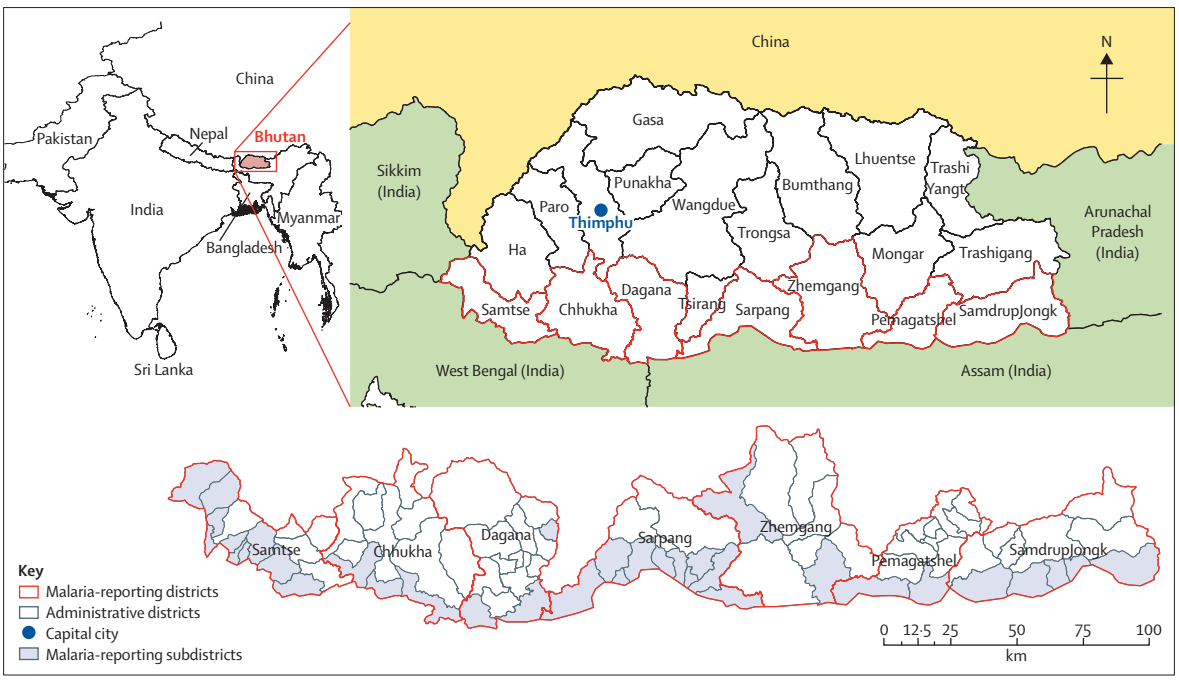

Figure 1: **Map of Bhutan showing malaria-reporting districts and subdistricts**

Malaria indicators

The total number of long-lasting insecticidal nets distributed from 2006 to 2014 was obtained from the VDCP. Long-lasting insecticidal nets were distributed to all the population residing in 36 subdistricts of seven districts. These subdistricts were selected based on the presence of malaria vectors. The average number of people per net was calculated for the years 2006, 2010, and 2013 (the mass distribution years) using the corresponding population of the 36 subdistricts. Population estimates used in this study were from publications from the National Statistical Bureau and the Office of the Census Commissioner of Bhutan (estimates of uncertainty regarding the population are not available).[13,14]

Test positivity rate was calculated by dividing the total number of malaria cases by the number of blood slide examinations and rapid diagnostic tests used, multiplied by 100 (and expressed as a percentage). Annual malaria incidence was calculated as the annual cumulative incidence of malaria cases reported by each district divided by the total population of the districts of the same year, multiplied by 1000.

Cost analysis

Data about the funds disbursed to the VDCP from international donors (The Global Fund to Fight AIDS, Tuberculosis, and Malaria; WHO; and the Government of India), and from the Royal Government of Bhutan, were obtained from the VDCP for the 2008–14 financial years. The costs of different commodities such as drugs, long-lasting insecticidal nets, chemicals and equipment (eg, pumps) for indoor residual spraying, microscopes, and rapid diagnostic tests, were obtained from the VDCP. All the funds were converted into US dollars (US$) for analysis. Costs were analysed based on different preventive measures, running of programme offices, and fuel for vehicles.

Statistical analysis and ethics clearance

Data were extracted into Microsoft Excel and Stata 12.1 was used for statistical analysis. Permission to use the data was approved by the Ministry of Health of the Royal Government of Bhutan. Since the datasets did not contain information about individual patients, ethical clearance was not required.

Role of the funding source

There was no funding source for this study. The corresponding author had full access to all the data in the study and had final responsibility for the decision to submit for publication.

Results

During the 9 years from 2006 to 2014, a total of 5491 cases of malaria were reported in Bhutan. Malaria in Bhutanese citizens accounted for 4377 cases: 80% of the total. In the Bhutanese population, the highest number of malaria cases was reported in 2006 with 1751 cases, followed by 883 cases in 2009. The lowest number of cases was 21 cases in 2014. In 2006, mono-infections with *P vivax* accounted for 895 (52%) of

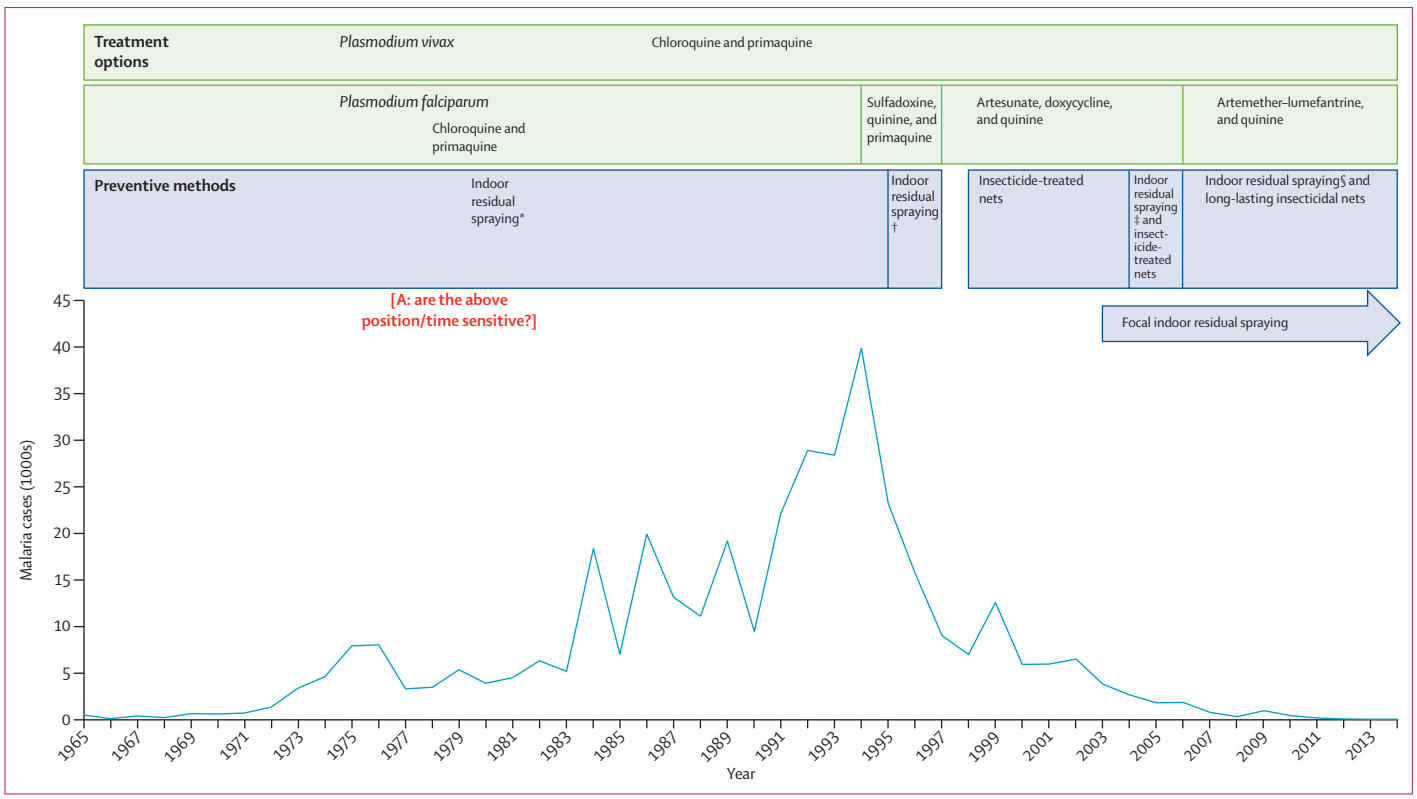

Figure 2: **Trend (blue line) in malaria case numbers in Bhutan, 1965–2014**
*With dichlorodiphenyltrichloroethane (DDT). †With deltamethrin. ‡One round per year. §Two rounds per year.

1751 cases, followed by *P falciparum* (733 [42%]) and mixed infections (124 [7%]). In 2014, *P falciparum* infected 11 (52%) of the 21 cases, and there were no mixed infections (table 1, figure 3).

Two types of foreign national status were recorded in the malaria patient records in Bhutan. The first group of foreigners includes those staying in Bhutan on a longer-term basis, mostly Indians working in developmental projects; the second category includes Indian nationals visiting Bhutan on day visits for business and employment. Malaria in the foreign nationals residing in Bhutan accounted for 384 (7%) of the total cases (table 1). In 2006, 116 cases were reported in this group, with numbers decreasing to 21 (6%) of 384 cases in 2014. Malaria in foreign national daily visitors accounted for 730 cases (13% of the total) during the study period. The highest number of cases reported in foreign national daily visitors was in 2006 (408 cases). After this timepoint, a decreasing trend occurred, with just three cases in 2014. Most of the infections were caused by *P falciparum* throughout the study period, with the exception of 2013, when *P vivax* was more frequent than *P falciparum*. No mixed infections were reported in foreign national daily visitors since 2011. Overall, foreign nationals (both those residing in Bhutan and daily visitors) contributed more than half of all malaria cases since 2013 (table 1).

A total of 15 deaths were recorded during the study period. The highest numbers of deaths were reported in 2006 and 2009, with four (27%) deaths each. No deaths have been reported since 2013. All deaths were caused by *P falciparum* or mixed infections (table 1). Women accounted for the most deaths (ten) and there were four deaths in children. Samdrup Jongkhar district reported the highest number of deaths (five), followed by Sarpang district (three).

Malaria indicators showed that numbers of blood samples collected for testing malaria parasites decreased during the study period, as did the test positivity rate (table 1). Annual malaria incidence fell during the study period from 12·9 cases per 1000 population in 2006 to less than one case per 1000 population from 2012 to 2014 (table 1).

During the study period, 357 091 new long-lasting insecticide-treated nets were distributed to residents in 36 subdistricts in endemic districts. In 2006, 93 269 were distributed, achieving an average of one long-lasting insecticidal net per 1·44 people. In 2010 and 2013, 99 697 and 99 617 long-lasting insecticidal nets were distributed, with averages of one net per 1·45 people in 2010 and one per 1·51 people in 2013. Follow-up distributions of long-lasting insecticidal nets were continued in the years between mass distributions as a mechanism to achieve universal population coverage (table 1).

	2006	2007	2008	2009	2010	2011	2012	2013	2014
Cases in the Bhutanese population									
Overall	1751	744	314	883	410	172	64	18	21
P falciparum	733 (42%)	274 (37%)	129 (41%)	433 (49%)	137 (33%)	83 (48%)	31 (48%)	8 (44%)	11 (52%)
Pvivax	895 (52%)	384 (52%)	142 (45%)	374 (42%)	239 (58%)	78 (45%)	31 (48%)	10 (56%)	10 (48%)
Mixed	124 (7%)	86 (12%)	43 (14%)	76 (9%)	34 (8%)	11 (6%)	2 (3%)	0	0
Cases in foreign nationals residing in Bhutan									
Overall	116	49	16	89	26	22	18	27	21
P falciparum	39 (34%)	14 (29%)	7 (44%)	41 (46%)	3 (12%)	4 (18%)	2 (11%)	5 (19%)	3 (14%)
P vivax	68 (59%)	30 (61%)	7 (44%)	39 (44%)	22 (85%)	14 (64%)	16 (89%)	21 (78%)	18 (69%)
Mixed	9 (8%)	5 (10%)	2 (13%)	9 (10%)	1 (4%)	15 (8%)	0	1 (4%)	0
Cases in foreign nationals who are daily visitors to Bhutan									
Overall	408	60	32	126	29	45	24	3	3
P falciparum	255 (63%)	28 (47%)	18 (56%)	99 (79%)	14 (48%)	35 (78%)	14 (58%)	1 (33%)	2 (67%)
P vivax	139 (42%)	26 (43%)	13 (41%)	24 (19%)	10 (35%)	10 (22%)	10 (42%)	2 (67%)	1 (33%)
Mixed	14 (3%)	6 (10%)	1 (3%)	3 (2%)	5 (17%)	0	0	0	0
Total deaths									
Overall	4	1	2	4	2	1	1	0	0
P falciparum	3 (75%)	0	1 (50%)	3 (75%)	0	1 (100%)	1 (100%)	0	0
Mixed	1 (25%)	1 (100%)	1 (50%)	1 (25%)	2 (100%)	0	0	0	0
Malaria indicators									
Population at risk	135 281	137 445	139 645	141 879	144 149	146 455	148 799	151 179	153 598
Long-lasting insecticidal nets	93 269	7413	9063	20 963	99 697	8942	11 041	99 617	7086
Long-lasting insecticidal nets per person	1·44	..	..	..	1·45	..	..	1·51	..
Blood sample collection	66 079	51 446	47 566	62 496	54 617	44 481	42 512	31 632	30 691
Malaria test positivity rate, %	2·8%	1·5%	0·7%	1·6%	0·8%	0·4%	0·2%	0·1%	0·1%
Annual malaria incidence per 1000 population	12·9	5·4	2·2	6·2	2·8	1·2	0·4	0·1	0·1

Data are n or n (%), unless otherwise indicated. *P falciparum=Plasmodium falciparum. P vivax=Plasmodium vivax.*

Table 1: **Trends in malaria infection and indicators in Bhutan, 2006–14**

Farmers were infected more than any other occupation group, accounting for more than half of the 961 cases in 2006 (table 2). A similar trend continued until 2012. However, since 2013, labourers have been infected more than other occupations, accounting for 29 (60%) of 48 cases in 2013 and 20 (44%) of 45 cases in 2014 (table 2). More than half of all cases in all years were in the 20–39 years age group and in men, for both types of infection (appendix pp 2–3).

The Global Fund to Fight AIDS, Tuberculosis and Malaria was the main donor supporting the Bhutan malaria programme. The highest amount was provided in the 2009–10 financial year by the Global Fund, amounting to US$1·23 million (73%) of the total $1·7 million. The Royal Government of Bhutan contribution was $0·17 million (12% of the total $1·4 million) in the 2008–09 financial year but increased to $0·22 million (32% of the total $0·7 million) in the 2012–13 financial year. Overall, the total funds provided to the VDCP decreased from the 2009–10 to 2012–13 financial years, but increased again in the 2013–14 financial year (table 3).

International funding was used solely for preventive and control measures, and ranged between $0·5 million in 2006 and $0·02 million in 2014 (appendix p 4). Most of the money was spent on the purchase of long-lasting insecticidal nets, with more than $0·45 million (89%) of the total spent on procuring these nets in 2006. The proportion of money spent on buying drugs fell from 1·4% ($0·07 million) in 2006 to just 0·08% ($15·34 million) in 2014. The proportionate cost of rapid diagnostic tests increased from 7·8% ($0·04 million of $0·5 million) of total costs in 2006 to 29·4% ($0·02 million of $0·05 million) in 2007 and fell again to 16·4% ($0·01 million) in 2008. There was a further reduction in 2009 (to 6·1%; $0·009 million of $0·2 million) but it increased gradually to reach 11% ($0·002 million of $0·02 million) in 2014. Other commodities, such as pumps for spraying chemicals for indoor residual spraying, and microscopes, were also purchased in different years (appendix p 4).

See Online for appendix

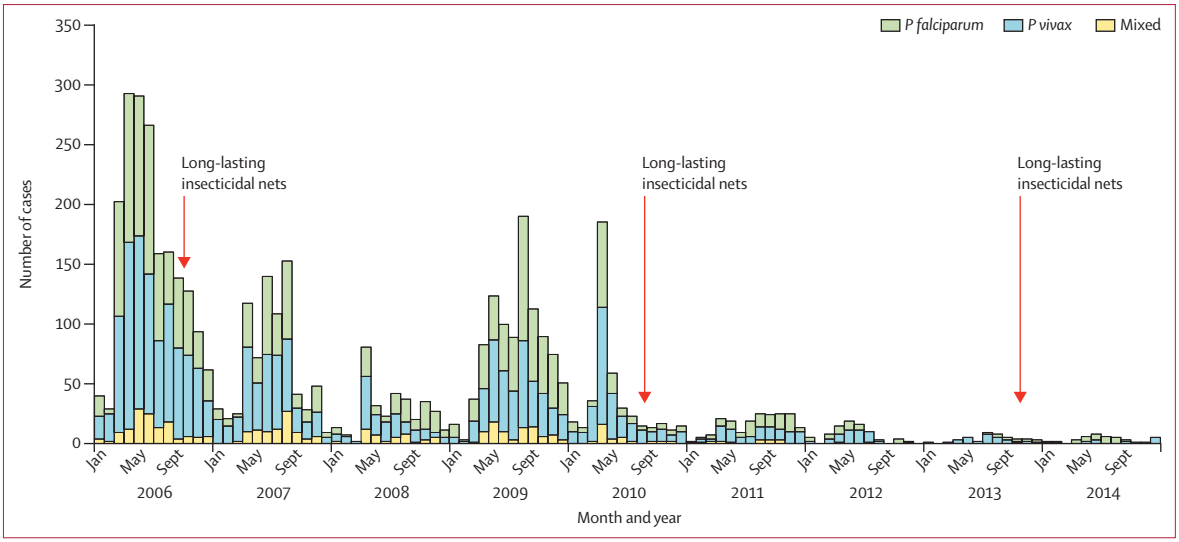

Figure 3: **Changes in types of malaria infection, treatment, and preventive measures in Bhutan, 2006–14**
P falciparum=Plasmodium falciparum. P vivax=Plasmodium vivax.

	2006 (n=1973)	2007 (n=798)	2008 (n=322)	2009 (n=968)	2010 (n=424)	2011 (n=217)	2012 (n=99)	2013 (n=48)	2014 (n=45)
Business person	68 (4%)	23 (3%)	14 (4%)	27 (3%)	6 (1%)	7 (3%)	2 (2%)	3 (6%)	2 (4%)
Farmer	1143 (58%)	452 (57%)	158 (49%)	410 (42%)	201 (47%)	83 (38%)	28 (28%)	7 (15%)	12 (27%)
Government employee	76 (4%)	30 (4%)	24 (7%)	34 (4%)	20 (5%)	19 (9%)	6 (6%)	2 (4%)	3 (7%)
Housewife	0	0	0	119 (12%)	35 (8%)	16 (7%)	13 (13%)	1 (2%)	0
Labourer	160 (8%)	77 (10%)	25 (8%)	69 (7%)	41 (10%)	22 (10%)	29 (29%)	29 (60%)	20 (44%)
Monk	9 (1%)	17 (2%)	4 (1%)	6 (1%)	4 (1%)	1 (1%)	0	0	0
Armed forces	177 (7%)	53 (7%)	30 (9%)	31 (3%)	17 (4%)	12 (6%)	2 (2%)	1 (2%)	1 (2%)
Student	340 (17%)	146 (18%)	67 (21%)	272 (28%)	100 (24%)	57 (26%)	19 (19%)	5 (10%)	7 (16%)

Data are n (%).

Table 2: **Occupations of patients with malaria infection in Bhutan, 2006–14**

Discussion

During the study period (2006–14) the number of *P falciparum* and *P vivax* malaria cases has decreased in Bhutan. This reduction corresponded with the mass distribution of long-lasting insecticidal nets and scaling up of indoor residual spraying, whereas other services such as diagnosis and treatment did not change during the study period. Cases dropped substantially following mass distribution of long-lasting insecticidal nets in 2006. However, cases resurged in 2009 and 2010, possibly because of the waning effect of the impregnated insecticide in the fibres of the nets. Reductions in malaria cases occurred and were maintained once new long-lasting insecticidal nets were distributed in 2010 and 2013. This success could be attributed, at least in part, to robust GIS-based surveillance systems that are in place, aligning with the global and regional strategies to eliminate malaria.[15,16]

This analysis suggests that the greatest threat to successful elimination efforts for Bhutan is importation of malaria, especially from India and other nearby countries. The two Indian states of Assam and West Bengal, which both border Bhutan, report the highest malaria burden in India.[17–21] The areas adjoining the international border in India are forested and are inhabited by indigenous people with poor access to

	2008–09	2009–10	2010–11	2011–12	2012–13	2013–14
Royal Government of Bhutan	$0·17 (12%)	$0·21 (12%)	$0·20 (26%)	$0·26 (29%)	$0·22 (32%)	$0·20 (21%)
Global Fund to Fight AIDS, Tuberculosis and Malaria	$1·0 (73%)	$1·23 (73%)	$0·38 (49%)	$0·42 (47%)	$0·28 (40%)	$0·60 (63%)
Government of India	$0·17 (12%)	$0·19 (11%)	$0·17 (22%)	$0·16 (18%)	$0·18 (26%)	$0·14 (14%)
WHO	$0·04 (3%)	$0·05 (3%)	$0·02 (3%)	$0·05 (6%)	$0·02 (3%)	$0·01 (2%)
Total	$1·4	$1·7	$0·78	$0·9	$0·7	$0·95

Data are millions of US$ (%).

Table 3: **Funding source for various malaria control activities in Bhutan**

Indian health facilities and services. These areas are subject to ethnic violence, which can impede health services efforts.[22] A strategy to address cross-border malaria with India is crucial to maintain the gains that have been achieved by Bhutan so far. Emigrants entering and staying overnight in Bhutan usually undergo blood examination for malaria parasites. However, day visitors do not undergo such a screening process, and therefore pose a substantial risk of onward transmission to the local population.[23] A potential risk of transmission of malaria across the borders by infected mosquitoes also exists, in view of the very close proximity of villages on both sides of the international border.

International donors were the major contributors to control and preventive measures, with funds spent on procuring antimalarial drugs, long-lasting insecticidal nets, indoor residual spraying, rapid diagnostic test kits, microscopes, and chemicals and pumps for indoor residual spraying. Funds from the Royal Government of Bhutan have mainly been used to pay the salaries of the officials working in the national programme, to run the offices, and for purchasing fuel for vehicles. International funding has allowed the ratio of one long-lasting insecticidal net per person to better the WHO-recommended ratio of one long-lasting insecticidal net per two people for malaria-endemic areas with low transmission.[24] This effort aims to interrupt local malaria transmission by mosquitoes despite a continued presence of malaria vectors and importation of parasites.[25] Recent prospective research has confirmed high coverage of long-lasting insecticidal nets in Bhutan with regular use.[26]

Bhutan received major funding from the Global Fund in grant round 4 (US$1·3 million) and grant round 7 (US$1·6 million) and from the Global Fund Transitional Funding Mechanism ($0·8 million).[7] The average international donor support worldwide to malaria-endemic countries for malaria control was less than $1 per person per year in 2007.[27] The corresponding figure for Bhutan was $2·2 per person per year, which is more than the $0-1 per person per year for 2009.[28] With the decreasing burden of malaria, international support will probably wane, exerting pressure on the Royal Government of Bhutan exchequer to fund malaria elimination activities. However, to maintain universal coverage of long-lasting insecticidal nets post-elimination, the Royal Government of Bhutan might need to consider two modalities through public–private partnership with cost sharing and social marketing of long-lasting insecticidal nets.

This study had some limitations. The cost calculations did not include the cost of expired drugs and rapid diagnostic tests, nor the cost of training malaria technicians or of quality assurance programmes. Furthermore, the cost analysis was restricted to long-lasting insecticidal nets and indoor residual spraying because no information could be obtained about other costs, such as the costs of buildings and equipment. The treatment of malaria was provided by physicians and other relevant health workers so these costs could not be included in the study because of difficulties in calculating the proportion of their time involved in providing treatments. The underlying cause of deaths from malaria could not be analysed because data were not recorded in the surveillance system.

In conclusion, the results of this study show that the malaria burden in Bhutan fell substantially during the study period, with high coverage of long-lasting insecticidal nets in the country. This study identified four foreseeable challenges that need national attention to maintain a malaria-free status in Bhutan after elimination. First, importation of malaria, especially from India, necessitates coordinated malaria control activities between Bhutan and India. Second, protection of the population in the endemic districts will necessitate complete coverage with long-lasting insecticidal nets and indoor residual spraying. Third, exploration of local funding modalities post-elimination will be needed in the event of a reduction in international funding. Last, initiation of public–private partnerships through cost sharing and social marketing of long-lasting insecticidal nets to maintain universal coverage of at-risk populations should be explored.

Contributors

KW and ACAC conceived the study. KW did data extraction, statistical analysis, interpreted the results, and drafted the report. ACAC assisted in statistical analysis and interpretation of results and was involved in the critical revision of the report. CB, MLG, GCK, and RN assisted in interpretation and revision of the report.

Declaration of interests

We declare no competing interests.

Acknowledgments

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CHAPTER FIVE

PREVALENCE OF ASYMPTOMATIC MALARIA AND BED NET OWNERSHIP AND USE IN BHUTAN, 2013: A COUNTRY EARMARKED FOR MALARIA ELIMINATION

Early diagnosis and prompt treatment remains the cornerstone of malaria control. In Bhutan, diagnosis is done using microscopic facilities at all levels of health care and is supplemented by rapid diagnostic tests (RDT). Additionally, the Vector-borne Disease Control Program (VDCP) of Bhutan commenced mass distribution of long lasting insecticidal nets (LLIN), with the aim of achieving universal coverage of all at-risk households in seven historically malaria-endemic districts in 2006. Focal indoor residual spraying (IRS) with pyrethroid is conducted in households in these districts, in March and September, just prior to and just after the monsoon season.

Malaria surveillance takes place through two methods: passive case detection and fever surveillance, which involves submitting from the field numbers of fever cases at the end of each week to the VDCP, through district offices. The latter serves as an important ongoing surveillance tool; an increase of fever cases over the weekly mean of the preceding five years triggers an investigation of a possible outbreak of malaria.

As Bhutan gears up to eliminate malaria in 2016, this study was undertaken with the aim of estimating the prevalence of asymptomatic malaria in four sub-districts, located in two districts of Samdrup Jongkhar and Sarpang, in August 2013. Additionally, levels of bed-net ownership and their use were assessed through interviews with the heads of households. This chapter is presented in a paper published in Malaria Journal.

Wangdi K, Gatton M, Kelly G, Clements A: **Prevalence of asymptomatic malaria and bed net ownership and use in Bhutan, 2013: a country earmarked for malaria elimination.** *Malar J* 2014, **13:**352.

MALARIA JOURNAL

RESEARCH Open Access

Prevalence of asymptomatic malaria and bed net ownership and use in Bhutan, 2013: a country earmarked for malaria elimination

Kinley Wangdi[1,2,3], Michelle L Gatton[4], Gerard C Kelly[2] and Archie CA Clements[1,2*]

Abstract

Background: With dwindling malaria cases in Bhutan in recent years, the government of Bhutan has made plans for malaria elimination by 2016. This study aimed to determine coverage, use and ownership of LLINs, as well as the prevalence of asymptomatic malaria at a single time-point, in four sub-districts of Bhutan.

Methods: A cross-sectional study was carried out in August 2013. Structured questionnaires were administered to a single respondent in each household (HH) in four sub-districts. Four members from 25 HH, randomly selected from each sub-district, were tested using rapid diagnostic tests (RDT) for asymptomatic *Plasmodium falciparum* and *Plasmodium vivax infection.* Multivariable logistic regression models were used to identify factors associated with LLIN use and maintenance.

Results: All blood samples from 380 participants tested negative for *Plasmodium* infections. A total of 1,223 HH (92.5% of total HH) were surveyed for LLIN coverage and use. Coverage of LLINs was 99.0% (1,203/1,223 HH). Factors associated with decreased odds of sleeping under a LLIN included: washing LLINs <six months and >nine months compared to washing LLINs every six months; HH in the least poor compared to the most poor socio-economic quintile; a HH income of Nu 5,001-10,000 (US$1 = Nu 59.55), and Nu >10,000, compared to HH with income of <Nu 1,500; HH located one to three hours walking distance to a health centre compared to being located closer to a health centre; a reported lack of knowledge as to what to do in event of LLINs being torn; and keeping LLINs in a box compared to keeping them hanging in the place of use. Factors associated with use of LLINs for purposes other than the intended use included: income group Nu 1,501-3,000 and HH located one to three hours walking distance from a health centre.

Conclusions: There was high coverage of LLINs in the study area with regular use of LLINs throughout the year. LLIN use for purposes other than malaria prevention was low. With high coverage and regular use of LLINs, and a zero prevalence of malaria infection found in historically high-risk communities during the peak malaria season, it appears Bhutan is on course to achieve malaria elimination.

Keywords: Malaria, Long-lasting insecticidal bet nets, Bhutan, Asymptomatic malaria

Background

Malaria remains one of the most important infectious diseases globally, with an annual incidence of 300–500 million cases and nearly one million deaths per year, imposing an enormous burden of suffering in tropical regions of the world [1,2]. However, there has been an estimated 17% global reduction of malaria incidence from 2000–2009 [3,4]. This improvement has been made possible by a substantial increase in investment in tackling malaria globally, in addition to rapid economic development and urbanization in many endemic countries. The scaling up of interventions has reduced malaria burden and transmission in many endemic areas [5-7]. Today, of the 99 malaria-endemic countries, 32 are pursuing an elimination strategy and 67 are controlling malaria [2,8,9]. The World Health Organization (WHO) Southeast Asia region (SEAR) has seen a particularly rapid reduction in malaria in the last decade [10].

Numbers of malaria cases have been dwindling in Bhutan in recent years. As a result, Bhutan announced a

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national strategy to eliminate malaria by 2016 [11]. Malaria is usually reported in seven districts in the southern belt of Bhutan, bordering India (Figure 1) [12]. The population at risk of malaria in these seven districts was 309,662 in 2013, including, by district: Chukha 85,608, Dagana 26,553, Pemagatshel 24,646, Samdrup Jongkhar 39,405, Samtse 68,579, Sarpang 43,915, and Zhemgang 20,956 [13]. These districts border the Indian states of Assam and West Bengal, which report among the highest numbers of cases of malaria by state in India [14-17]. In these border areas, the climate is sub-tropical with abundant rainfall in the summer months, providing an environment that is conducive for multiplication of malaria vectors. *Anopheles pseudowillmori* and *Anopheles culicifacies* are suspected to be the main vectors in Bhutan [11]. The porous borders with the malaria-endemic Indian states of Assam and West Bengal permit easy movement of people between the two countries for employment opportunities and business, presenting a high risk of malaria importation into Bhutan [18].

As Bhutan embarks on the path to malaria elimination, the key focus of the malaria programme includes ensuring full population coverage of preventive measures such as long-lasting insecticidal bed nets (LLINs) and indoor residual spraying (IRS), and access to treatment in target areas. The defining aspects of malaria elimination programmes are: detection of all malaria cases, prevention of onward transmission, management of malaria foci and management of importation of malaria parasites. Elimination needs a relentless focus on surveillance and response and especially on the identification and rapid elimination of foci of infections, both symptomatic and asymptomatic [19]. The malaria surveillance system currently used in Bhutan involves passive reporting of fever and malaria cases and it is not designed to detect asymptomatic cases, which are important contributors to transmission and potential resurgence. There is a need in elimination programmes for the identification of foci of parasite transmission through active surveillance. There is also a need to focus on preventing importation of malaria through proactive case detection at borders, screening of high-risk migrants and the implementation of cross-border initiatives [6,20,21].

A primary front-line malaria prevention strategy in Bhutan includes the mass distribution of LLIN in the endemic districts of the country. Between 2006 and 2010, the Vector-borne Disease Control Programme (VDCP) under the Department of Public Health (DoPH) of the Ministry of Health (MoH) of Bhutan, distributed over 228,053 LLINs in these districts, supported by grants from the Global Fund to Fight AIDS, Tuberculosis and Malaria (GFATM) [11]. The success of LLINs as a means of eliminating malaria depends on the willingness of the people to use the LLINs regularly. Maintaining coverage

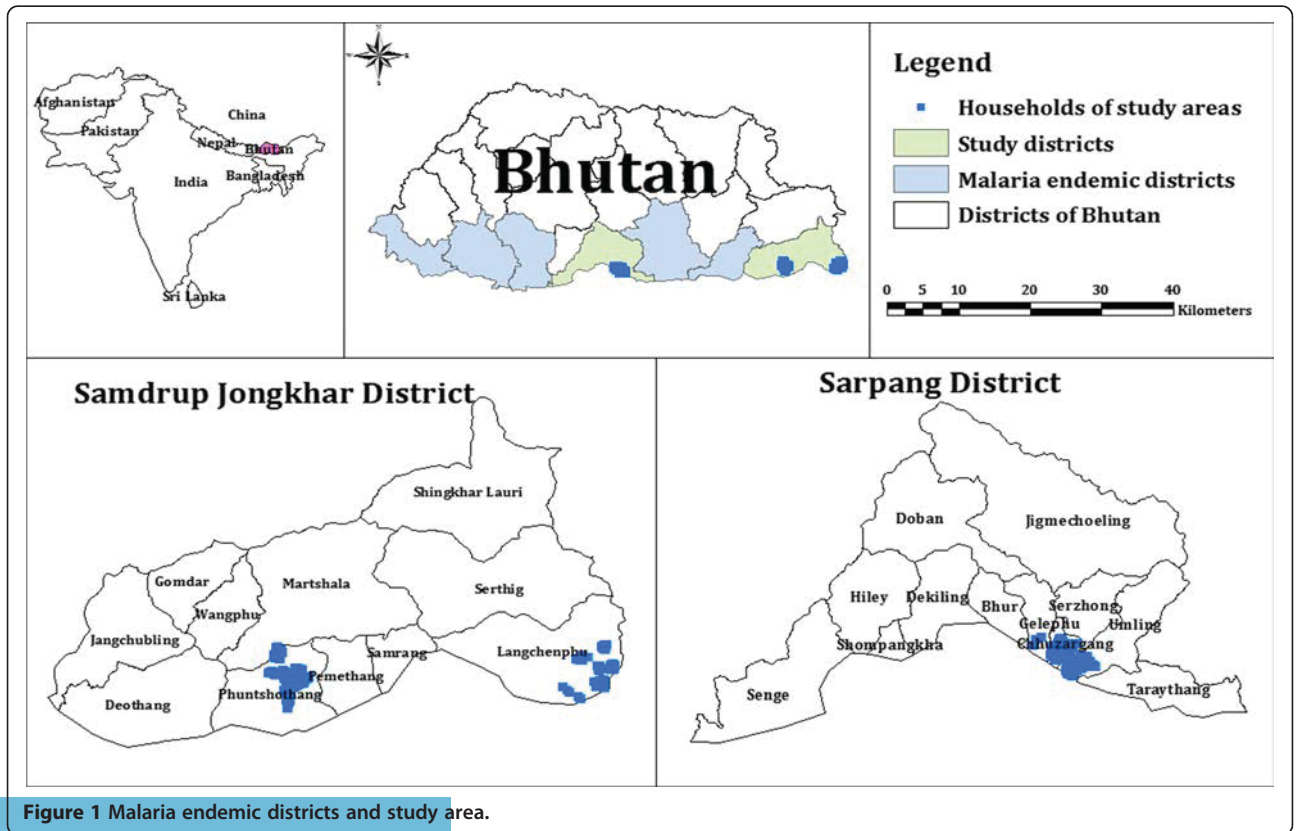

Figure 1 Malaria endemic districts and study area.

and use of LLINs, preventing importation of malaria from India, and the presence of possible reservoirs among people with asymptomatic infections, are the major challenges to malaria elimination in Bhutan.

This study aimed to assess the coverage, use and ownership of LLINs and factors associated with LLIN use in four selected sub-districts of Sarpang and Samdrup Jongkhar, two historically high-incidence districts of Bhutan on the border with India. Additional aims were to quantify the prevalence of asymptomatic infection with *Plasmodium falciparum* and *Plasmodium vivax* infection in the four sub-districts at a single time point during the peak malaria season, and to assess Bhutan's progress towards malaria elimination.

Methods

Definitions

Definitions for several terms used in this study are provided below:

Household (HH): a unit headed by a male or female with his/her dependents and spouse, and who share a cooking pot/common eating place and sleep under one roof.

LLIN: nets that were distributed by the VDCP, which had deltamethrin impregnated in the fibers of the net and which do not need additional impregnation throughout the entire four-year life span of the net.

Regular use of LLINs: all members of the HH sleep under LLINs, including guests, throughout the year.

LLIN ownership: HH having the LLINs distributed by VDCP.

Asymptomatic malaria: individuals returning a positive malaria diagnostic test result but not presenting with any of the classical symptoms such as fever, chills and rigor, sweats, headaches, nausea and vomiting, body aches and malaise.

Study area and participant recruitment

Samdrup Jongkhar and Sarpang districts were selected for the study because these districts have persistently had the highest incidence of cases of malaria in Bhutan over the last seven years (Figure 2). The rest of the districts did not report any, or reported very few cases in the last few years. Of note, even the highest-incidence areas of Bhutan are classified as low-endemicity areas, so the highest incidence areas are also likely to be those with the highest prevalence of asymptomatic infections (unlike the scenario in many highly endemic, stable-transmission areas of the world). Two sub-districts were selected from each district on the basis of them having the highest numbers of malaria cases in their respective district. Hence the study specifically targeted areas where malaria was most commonly reported. Attempts were made to survey every HH within the selected sub-districts. Any HH that was unattended on the day of interview was not included in the study. A single respondent, usually the head of the HH, was selected to complete a personal interview with a member of the study team. However, if the HH head was absent on the day of interview, the next eldest person was selected. During the interview, respondents were administered a pretested, structured questionnaire on household LLIN ownership and use.

In addition to the HH survey, a sample of residents was asked to provide a blood sample for malaria diagnosis. To select this sample random household selection was conducted from a geographical reconnaissance (GR) dataset housed in a spatial decision support system (SDSS) that uses the geographical information system (GIS) *Quantum* GIS (QGIS) as its platform. The "Research Tools - Random Selection" geo-processing application within QGIS was used to randomly select 25 HH located within each selected sub-district from the GR dataset. Within each selected HH, two adults and two children (<12 years of age) were selected. The inclusion criteria were: (1) residing in the locality for at least eight weeks prior to the date of testing; and, (2) willingness to undergo the blood test after signing the informed consent form or consent being obtained from parents or guardians of the children. Exclusion criteria were: (1) suffering from other diagnosed co-morbidities; (2) pregnancy; and (3) received/receiving treatment for either *P. falciparum* or *P. vivax* infection during the last eight weeks. Each participant provided a blood sample for malaria diagnosis using the First Sign Para-View 2 rapid diagnostic test (RDT) (Diagnova, Division of RFCL Limited, India).

Data collection

The survey was carried out in August 2013, coinciding with the historical peak of the malaria transmission season. Based on logistical criteria, blood samples for malaria diagnosis were to be collected from 400 individuals from 25 HH each in four sub-districts and four participants from each HH. The questionnaire used in the HH survey contained questions relating to: (1) characteristics of the respondent (age, gender, whether the respondent was the head of the HH, and occupation); (2) the number of HH members and their age and sex; (3) indicators of socio-economic status and wealth of the HH such as house type, income and ownership of assets (television, refrigerator, electric rice cooker and curry cookers, car, power tiller, rice mill, power chain and bicycle); and (4) ownership and regular use of LLINs based on a measure of individual use.

Statistical analysis

Data entry was done in Microsoft Excel and analysis was carried out using the statistical package STATA 12.1 (Stata Corporation, College Station, Texas, USA). The primary outcomes of interest were LLIN ownership, LLIN usage and use of LLINs for purposes other than protection

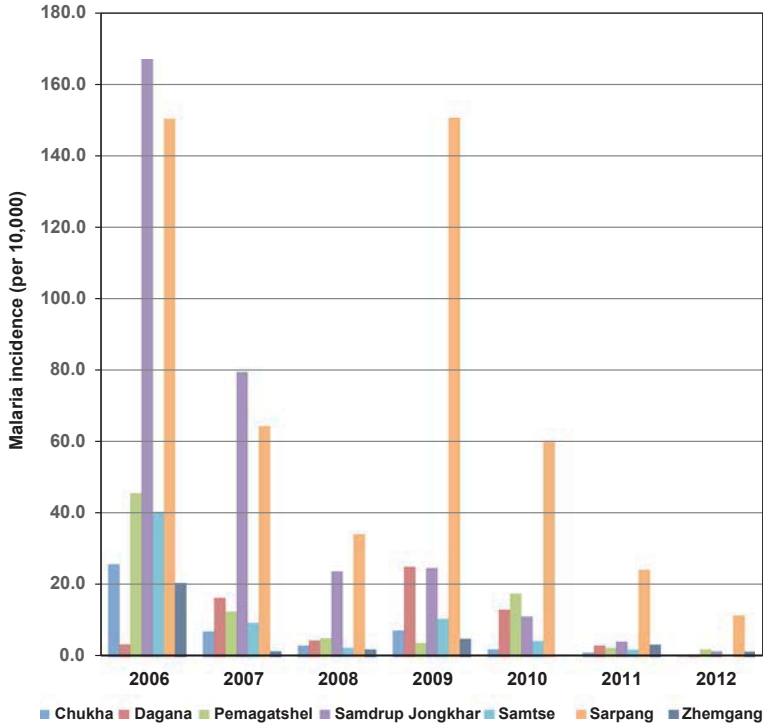

Figure 2 Malaria trend (incidence) in seven endemic districts of Bhutan from 2006–2012. (Source: Malaria cases VDCP, Department of Public Health, Ministry of Health; Population of districts from National Statistical Bureau, Bhutan).

against the bite of mosquitoes. The study aimed to determine the frequency and distribution of socio-economic characteristics of the HH surveyed and potential factors associated with LLIN ownership and usage.

Principal component analysis (PCA) was used to derive a socio-economic index based on the types of house and ownership of HH items such as television, refrigerator, electric rice cooker and curry cooker, car, power tiller, rice mill, power chain and bicycle. Using the factor scores from the first principal component as weights, a HH socio-economic score variable was constructed. The scores were used to classify the HH into five broad socio-economic quintiles: least poor, less poor, poor, more poor and most poor.

Bivariate and multivariable logistic regression models for LLINs use and use of LLINs for purposes other than malaria prevention were built using backward elimination to identify significant covariates. An alpha level of 0.10 was used to determine which variables remained in the model. A value of $p \leq 0.05$ was considered significant. All explanatory variables in the multivariable model were tested to ensure there was no multi-collinearity in the final model.

Ethical clearance

Ethical approval for this study was provided by the Research Ethics Board of Health (REBH), MoH, Royal Government of Bhutan (reference number: REBH/Approval/2013/014) and the Human Research Ethics Committee of the University of Queensland (reference number: 2013000884). Verbal permission from local community leaders was sought prior to conducting the survey and examination of blood using RDTs. Written informed consent was obtained from the head of each HH or questionnaire respondent. Interviewers explained the general purpose, benefits, and any risks of the survey to each respondent in his or her local language, and respondents had the right to refuse participation in the survey at any point. Written consent for the participants undergoing the blood test was obtained. For child participants, consent for the testing of blood was obtained from a parent or guardian.

Results

Result of blood test for malaria infection using rapid diagnostic test

Malaria diagnosis using the RDT returned valid results for 380 individuals. Children (≤12 years) made up 48.9% (186) of participants while 41.6% (158) were male. All the RDTs were negative for malaria parasites, including either *P. falciparum* or *P. vivax*. Post-hoc analysis, using an exact hypothesis test for a binomial proportion when the proportion is low, indicates that having achieved a sample size of 380 and zero positives, this showed that

the prevalence of asymptomatic infection in the population was statistically significantly less than 1% (two-sided test for prevalence <1%, p = 0.037; 95% binomial exact CI for the observed prevalence 0-0.0097). This provided a satisfactory degree of precision to establish a very low prevalence of malaria infection in the population.

Demographic characteristics of respondents

Out of a total of 1,322 HH in the four subdistricts (Chuzergang 360, Langchenphu 302, Phuntshothang 359 and Umling 301), 1,223 HH (92.5% of total HHs) were administered the questionnaire. The numbers of HH included in each sub-district were: Langchenphu 23.8% (291); Phuntshothang 26.2% (320); Chuzergang 27.0% (330); and, Umling 23.1% (282). Almost 70% (846) of the 1,223 interviewees were heads of HH, and 52.0% (635) were female. The median age of respondents was 42 years (range 14-89 years). The most frequent occupation of the respondents was farming (77.3%, 942 respondents), followed by civil service (9.4%, 115 respondents). Eighty-five per cent of the interviewees (1,040) were married, whereas 8.8% (108) were single.

Socio-demographic characteristics of households

The total population represented by the HH survey was 5,379 with females making up 51.4% (2,767) of the sample. Children aged < five years comprised 10.3% (555) of the represented population (Table 1). The average number of occupants per HH was 4.4 (range 1-12). The most frequent category of HH income was < Nu 1,500 per month (US$1 = Nu 59.55) (38.9%, 474 respondents), followed by Nu 1,501-3,000 (27.2%, 331 respondents). Only 8.9% (108) of HH had an income > Nu 10,000 per month. The most frequent housing construction type was brick and cement (38.5%, 470 respondents), followed by wood and mud (29.7%, 363 respondents). For ownership of HH items indicative of socio-economic status, the most common item was an electric rice cooker (89.3%, 1,090 respondents), followed by an electric curry cooker (79.7%, 973 respondents). Fifty-nine per cent (724) of the HH owned a television and 51.2% (625) of HH owned a refrigerator. Three per cent (40) of HH owned other items such as a car, rice mill, tractor, or power chain. A majority of the HH (70.2%; 856) were located within one hour walking distance and 27.3% (333) of HH were located one to three hours' walking distance from the health centre (Table 1).

Long-lasting insecticide-treated nets coverage and use

A high coverage of LLINs was reported among the surveyed HH, with 99.0% (1,203) of HH having LLINs. Most people within the HH (93.9%; 1,145) reported they regularly slept under LLINs, and 98.4% (1,190) of respondents slept under LLINs the night before the survey. Among the

Table 1 Attribute of household and characteristics of long-lasting insecticide-treated net ownership and use in four sub-districts in Bhutan, 2013

Attribute	Number	%
Male	2,612	48.6
Female	2,767	51.4
Children <5 years	555	10.3
Children 6-12 years	902	16.8
Young adults 13-24 years	1,090	20.3
Adults >25 years	2,831	52.6
Income*		
<Nu 1,500	474	38.9
Nu 1,501-3,000	331	27.2
Nu 3,001-5,000	184	15.1
Nu 5,001-10,000	122	10.0
>Nu 10,000	108	8.9
Ownership of household items		
Television	724	59.3
Refrigerator	625	51.2
Rice cooker	1,090	89.3
Curry cooker	973	79.7
Boiler	167	13.7
Other things	40	3.3
Types of house		
Hut**	223	18.3
Wood and mud	363	29.7
Stone and wood	166	13.6
Bricks and cement	470	38.5
Socio-economic quintile of household		
Most poor	282	23.1
More poor	208	17.1
Poor	297	24.3
Less poor	373	30.6
Least poor	60	4.9
LLINs owned by household		
Yes	1,203	99.0
No	12	1.0
Members of households sleeping regularly under LLINs		
Yes	1,145	93.9
No	75	6.1
Period when LLINs were not used		
Summer months	10	14.7
Both summer and winter months	4	5.9
Winter months	53	77.9
Others	1	1.5

Table 1 Attribute of household and characteristics of long-lasting insecticide-treated net ownership and use in four sub-districts in Bhutan, 2013 *(Continued)*

Respondents slept under LLINs the night before the survey		
Yes	1,190	98.4
No	20	1.7
Frequency of LLIN washing		
<6 months	27	2.2
Every six months	806	67.0
7-8 months	15	1.3
>9 months	164	13.6
Never	191	15.9
Action taken in case net was torn		
Sleep without bed nets	5	0.4
Repair the bed nets	1,135	94.3
Buy a new bed net	32	2.7
Do not know	23	1.9
Hanging of LLINs kept during day		
Hang in the sleeping place	1,161	96.6
Keep in cardboard or box	36	3.0
Keep in other place	4	0.3
Location of households from the nearest health centre		
<1 h walking distance	856	70.2
1-3 h walking distance	333	27.3
>3 h walking distance	31	2.5

*US$ 1 = Nu 59.55.
**made of bamboo which can be woven or smashed bamboo.

respondents who reported that they did not always sleep under LLINs (75 HH), 77.9% (53) said they stopped sleeping under LLINs during the winter months. LLINs were washed every six months in 67.0% (806) of HH while 15.9% (191), never washed. In the event of a net being torn, 94.3% (1,135) reported that they would repair the net and 2.7% (32) reported that they would buy a new net. Most respondents (96.6%) reported that they kept the LLINs hanging in the sleeping area during the day (Table 1).

Factors associated with long-lasting insecticide-treated net use

The HH that washed LLINs more frequently than every six months (OR = 0.2, <0.0001, AOR = 0.2, p = 0.026), less frequently than every nine months (OR = 0.2, p < 0.0001; AOR = 0.1, p < 0.0001) and that never washed LLINs (OR = 0.5, p = 0.03; AOR = 0.5, p = 0.10) were less likely to sleep under LLINs compared to HH that washed their nets as per manufacturer instructions (every six months) (Table 2).

The respondents of HH in the least poor socio-economic quintile were less likely to sleep under a LLIN (OR = 0.1, p < 0.0001; AOR = 0.2 p = 0.002) compared to the poorest quintile. Similar results were obtained when income was used as an explanatory variable: respondents of HH with an income of Nu 5,001-10,000 (OR = 0.4, p = 0.007; AOR = 0.3, p = 0.027) and Nu >10,000 (OR = 0.2, p < 0.0001; AOR = 0.1, p < 0.0001) were less likely to use LLINs as compared to HH with an income of Nu <1,500.

Household located one to three hours walking distance from the nearest health centre were less likely to use LLINs compared to HH located < one hours walking distance (OR = 0.5, p = 0.012 AOR = 0.3, p = 0.002). In the event of LLINs being torn, HH where the respondent reported that they did not know what to do (OR = 0.1, p < 0.0001; AOR = 0.1, p < 0.0001) and who reported that they would buy new nets (OR = 0.2, p < 0.0001) were less likely to sleep under LLINs as compared to HH who said they would repair torn LLINs. The HH who kept their LLINs in a box were less like to sleep under LLINs (OR = 0.1, p < 0.0001; AOR = 0.1, p < 0.000) compared to those who hung the LLIN in the sleeping area during the day (Table 2).

Use of long-lasting insecticide-treated nets for non-intended purposes

It was reported that LLINs were used for purposes other than malaria prevention by 4.3% (50) of HH. The HH in the poor and less poor socio-economic quintiles were less likely to use LLINs for non-intended purposes compared to the poorest quintile (OR = 0.4, p = 0.018 and OR = 0.1, p < 0.0001), respectively. However, after adjusting for other variables, the associations were not significant (AOR = 0.9, p = 0.70 and AOR = 0.3, p = 0.09, respectively). The HH located one to three hours' walking distance from the nearest health centre were more likely to use LLINs for non-intended purposes (OR = 8.8, p < 0.0001 and AOR = 10.4, p < 0.0001, respectively) than HH located < one hours' walking distance from a health centre. Incomes of HH, number of HH members, action taken in case of LLINs being torn and hanging of LLINs during the day in different locations were not statistically associated with use of LLINs for non-intended purposes (Table 3).

Discussion

This study focused on LLIN coverage and use in areas of Bhutan that traditionally had the highest incidence of reported malaria. In these areas, numbers of malaria cases reported through passive case detection has continually decreased. However, little is known about asymptomatic malaria since active case detection has

Table 2 Factors associated with use of long-lasting insecticide-treated nets in Bhutan, 2013

Net use	Unadjusted		Adjusted	
	Odds ratio (95% CI)	P value	Odds ratio (95% CI)	P value
Washing of LLINs (1,172)				
Every 6 months (801)	Ref			
<6 months (26)	0.2 (0.1, 0.4)	<0.0001*	0.2 (0.1, 0.8)	0.026*
>9 months (164)	0.2 (0.1, 0.4)	<0.0001*	0.1 (0.1,0.3)	<0.0001*
Never washed (191)	0.5 (0.2, 0.7)	0.03*	0.5 (0.2, 1.1)	0.10
Socio-economic quintile (1,200)				
Most poor (278)	Ref		Ref	
More poor (205)	1.0 (0.4, 2.4)	0.97	0.8 (0.3, 2.2)	0.65
Poor (295)	0.7 (0.3, 1.5)	0.34	0.5 (0.2, 1.2)	0.13
Less poor (363)	1.1 (0.5, 2.3)	0.91	0.9 (0.3, 2.7)	0.87
Least poor (59)	0.1 (0.1, 0.3)	<0.0001*	0.2 (0.1, 0.5)	0.002*
Household members (1,189)				
< 3 members (419)	Ref		Ref	
4-6 members (610)	1.1 (0.7, 1.9)	0.66	1.0 (0.5, 1.9)	0.98
7-9 members (169)	1.9 (0.8, 4.8)	0.15	2.5 (0.8, 7.7)	0.11
Household income per month (1,199)				
< Nu 1,500 (472)	Ref		Ref	
Nu 1,501-3,000 (327)	1.5 (0.7, 3.2)	0.32	0.8 (0.3, 2.0)	0.66
Nu 3,001-5,000 (180)	4.1 (1.0, 17.9)	0.06	2.2 (0.5, 10.6)	0.33
Nu 5,001-10,000 (117)	0.4 (0.2, 0.8)	0.007*	0.3 (0.1, 0.9)	0.027*
>Nu 10,000 (103)	0.2 (0.1, 0.3)	<0.0001*	0.1 (0.04, 0.3)	<0.0001*
Location of households from the nearest health centre (1,200)				
<1 hrs (840)	Ref		Ref	
1–3 hrs (329)	0.5 (0.3, 0.9)	0.012*	0.3 (0.1, 0.7)	0.002*
>3 hrs (31)	1			
Action taken if LLINs are torn (1,182)				
Repair the LLINs (1,122)	Ref		Ref	
Do not know (22)	0.1 (0.1 0.3)	<0.0001*	0.1 (0.03, 0.3)	<0.0001*
Buy new one (38)	0.2 (0.1, 0.3)	<0.0001*	0.5 (0.2, 1.5)	0.24
Hanging of LLIN during day (1,184)				
Hang in sleeping area (1,147)	Ref		Ref	
Keep in the box (33)	0.1 (0.04, 0.2)	<0.0001*	0.1 (0.1, 0.4)	<0.0001*
Other place (4)	0.1 (0.02, 1.4)	0.09	0.3 (0.02, 3.8)	0.33

Unadjusted odds ratio (OR) was obtained from bivariate logistic regression and adjusted odds ratio (AOR) was obtained from multivariable logistic regression.
*significant at $p < 0.05$.

not been undertaken. As part of this study, 380 participants provided blood samples to reveal a zero prevalence of asymptomatic malaria, which is encouraging for malaria elimination efforts. However, a larger sample would be required to provide clear evidence of cessation of malaria transmission.

This study found a very high coverage of LLINs in four sub-districts of Bhutan. The VDCP strategy of distributing free LLINs to achieve a target of universal coverage in the malaria endemic districts of Bhutan appears to have worked well. The previous mass distribution of LLINs in the study sub-districts was carried out in 2010 and the most recent round of mass distribution of LLINs was carried out in December 2013, soon after the current study was conducted, which is likely to further enhance LLIN coverage in the malaria-endemic districts of Bhutan. A

Table 3 Factors associated with use of long-lasting insecticide-treated nets for non-intended purposes in Bhutan, 2013

Net used for other purpose	Unadjusted		Adjusted	
	Odds ratio (95% CI)	P value	Odds ratio (95% CI)	P value
Wealth quintile (1,200)				
Most poor (278)	Ref		Ref	
More poor (205)	0.7 (0.3, 1.4)	0.26	0.8 (0.3, 1.9)	0.61
Poor (295)	0.4 (0.2, 0.9)	0.018*	0.9 (0.4, 1.2)	0.70
Less poor (363)	0.1 (0.03, 0.3)	<0.0001*	0.3 (0.1, 1.2)	0.09
Least poor (59)	0.2 (0.02, 1.4)	0.1	1.0 (0.1, 8.8)	0.98
Household members (1,189)				
< 3 members (419)	Ref		Ref	
4-6 members (610)	1.0 (0.6, 1.8)	1.0	1.2 (0.6, 2.4)	0.67
7-9 members (169)	0.4 (0.1, 1.2)	0.1	0.4 (0.1, 1.5)	0.17
Household income per month (1,199)				
< Nu 1,500 (472)	Ref		Ref	
Nu 1,501-3,000 (327)	0.9 (0.5, 1.6)	0.64	3.2 (1.5, 7.1)	0.003*
Nu 3,001-5,000 (180)	0.6 (0.2, 1.4)	0.23	2.2 (0.7, 6.7)	0.17
Nu 5,001-10,000 (117)	0.1 (0.02, 1.1)	0.06	0.5 (0.1, 4.1)	0.53
>Nu 10,000 (103)	0.2 (0.02, 1.3)	0.09	1.4 (0.1, 13.1)	0.79
Location of households from the nearest health centre (1,169)				
<1 hrs (840)	Ref		Ref	
1–3 hrs (329)	8.8 (4.3, 18.2)	<0.0001*	10.4 (4.5, 24.1)	<0.0001*
Action taken if LLINs are torn (1,182)				
Repair the LLINs (1,122)	Ref		Ref	
Do not know (22)	1.1 (0.2, 8.4)	0.92	1.5 (0.2, 12.4)	0.71
Buy new one (38)	1.3 (0.3, 5.4)	0. 75	0.8 (0.1, 6.5)	0.80
Keeping LLIN during day (1,184)				
Hang in sleeping area (1,147)	Ref		Ref	
Keep in the box (33)	1.6 (0.4, 6.8)	0.53	1.8 (0.4, 9.2)	0.48

Unadjusted odds ratio (OR) was obtained from bivariate logistic regression and adjusted odds ratio (AOR) was obtained from multivariable logistic regression.
*significant at $p < 0.05$.

high coverage of LLINs with consistent use of LLINs throughout the year is important to prevent and protect the population from malaria infection and to achieve elimination by 2016, which is the stated national goal of Bhutan.

The percentage of HH sleeping under LLINs regularly was found to be 93.9%, with the reported percentage dropping during the winter months. As reported in other studies, the main reason for not sleeping under LLINs was the perception that there were no mosquitoes during the winter months [22]. Although no malaria infections were detected in this study, importation is a constant threat so there is a need to sensitize the community to the importance of LLIN adherence throughout the year, with emphasis on the risk of malaria transmission occurring year-round. This may require routine HH visits by trained community health workers, or providing education during the mass distributions of LLINs, mass IRS rounds, or regular dedicated malaria awareness campaigns.

LLIN maintenance is an important issue for malaria elimination. Even though 67% of the respondents washed their net regularly (at least once every six months), almost 16% never washed their LLINs. Washing at regular time intervals is important because dirt and other particles on the LLINs may act as a barrier, reducing the effectiveness of the chemicals on the net. The respondents who washed LLINs very frequently (<six months), less frequently (>nine months) and who never washed were less likely to sleep under LLINs as compared to respondents that washed LLINs as per the manufacturers' guidelines (every six

months). This might reflect that a stronger commitment to use LLINs is accompanied by a commitment to maintain them. Most of the respondents (94.27%) said they would repair nets if they were torn. The repair of minor tears of LLINs can help increase the effective lifespan of LLINs. Washing of LLINs and repair of LLINs are important indicators of the care and maintenance of LLINs. Hanging LLINs during the day has been identified as a factor strongly associated with LLIN use [23,24]. Most of respondents, 96.6% hung their LLINs in the sleeping area during the day time. This supports the assessment that the use of LLINs in the study area was high. Other benefits of keeping the net hanging include that chemicals on the LLINs will deter mosquitoes from coming into the rooms, having an additional preventive effect on biting [25,26].

HH in the least poor socio-economic quintile were less likely than the poorest HH to use LLINs, and similar findings were reported in other studies [27-29]. The houses in the higher socio-economic quintiles were better constructed, with a likely perception of mosquitoes being less able to enter the house. These HH could be using other protective measures such as mosquito repellents or installation of screens on windows and doors; however this information was not collected during the study. Households located one to three hours' walking distance from the nearest health centre were less likely to use LLINs compared to HH located one hour from the health centre, possibly because HH that were nearer to the health centres are better informed on the risks of getting malaria if LLINs were not used regularly. Similar findings have been made in other studies [30].

It has been reported that mosquito nets have been used for purposes other than malaria protection, including fencing gardens, storing grains, drying and as fishing nets [22,23,31]. It has also been suggested that this is the case in the endemic districts of Bhutan. However, reported use of LLINs for other purposes in the study was low, as has been found elsewhere [32], most likely reflecting a high degree of understanding of the importance of LLINs in preventing malaria.

There are some potential limitations to the current study which should be considered. Firstly, LLINs ownership and use by HH were based on self-report without verification. Secondly, the respondents may have over-reported net use, or under-reported the use of LLINs for alternate purposes, on the basis of social desirability, especially given that the interview was conducted by the malaria technicians of the health centers of the catchment area. In terms of using RDTs for malaria diagnosis, while the sensitivity and specificity of the RDT are reported to be high [33], however reduced sensitivity might occur with low parasite densities and exposure of the RDT to extreme temperatures [34-37].

Conclusions

A zero prevalence of asymptomatic malaria and a high coverage of LLINs was reported in the study area with regular use throughout the year. The use of LLINs for non-intended purposes was low. Never-the-less, there is a need to educate the small proportion of people not sleeping under LLINs, particularly in the winter months, to use LLINs throughout the year, and to promote regular washing of LLINs among 16% of respondents who never wash their LLINs. Based on the findings of the current study, it appears that Bhutan is on course to achieve malaria elimination.

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

KW and ACAC conceived the study. KW undertook field work, statistical analysis and interpretation of results and drafted the manuscript. ACAC assisted in statistical analysis, interpretation of results and was involved in the critical revision of the manuscript. MLG assisted in interpretation and revision of the manuscript. GCK assisted in field work planning and in revision of manuscripts. All authors read and approved the final manuscript.

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CHAPTER SIX
DEVELOPMENT AND EVALUATION OF A SPATIAL DECISION SUPPORT SYSTEM FOR MALARIA ELIMINATION IN BHUTAN

Spatial decision support systems (SDSS) provide enhanced support for decision making and information management, for decisions that have a spatial dimension. Paper-based maps have been used globally for planning malaria interventions since the eradication efforts in the 1960s. More recently, electronic geographic information systems (GIS), which permit input, storage, manipulation, and output of geographic information, have provided a powerful suite of tools for managing data in the context of the prevention, control and elimination of malaria.

This chapter describes the development of a SDSS based on the open-source Quantum geographical information system (QGIS). The aim of developing the SDSS was to provide the Vector-borne Disease Control Program (VDCP) of Bhutan an alternative approach to managing routine operations of the programme (delivery of long lasting insecticidal nets (LLINs) and indoor residual spraying (IRS)) as well as conducting surveillance. Following development of the SDSS, it was piloted in two sub-districts of Samdrup Jongkhar for carrying out mass distribution of LLINs in December 2013 and IRS in April 2014. The SDSS was also deployed for carrying out detection of residual malaria infections within a one kilometer raidus of index malaria cases through reactive case detection (RACD). Acceptability and utility of the SDSS were evaluated through informant interviews of the end users (n=11) including officials at the program level (n=4), district manager (n=1) and field workers (n=6) in December 2014. This chapter is presented as a paper published in Malaria Journal.

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Malaria Journal

RESEARCH Open Access

Development and evaluation of a spatial decision support system for malaria elimination in Bhutan

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Abstract

Background: Bhutan has reduced its malaria incidence significantly in the last 5 years, and is aiming for malaria elimination by 2016. To assist with the management of the Bhutanese malaria elimination programme a spatial decision support system (SDSS) was developed. The current study aims to describe SDSS development and evaluate SDSS utility and acceptability through informant interviews.

Methods: The SDSS was developed based on the open-source Quantum geographical information system (QGIS) and piloted to support the distribution of long-lasting insecticidal nets (LLINs) and indoor residual spraying (IRS) in the two sub-districts of Samdrup Jongkhar District. It was subsequently used to support reactive case detection (RACD) in the two sub-districts of Samdrup Jongkhar and two additional sub-districts in Sarpang District. Interviews were conducted to ascertain perceptions on utility and acceptability of 11 informants using the SDSS, including programme and district managers, and field workers.

Results: A total of 1502 households with a population of 7165 were enumerated in the four sub-districts, and a total of 3491 LLINs were distributed with one LLIN per 1.7 persons. A total of 279 households representing 728 residents were involved with RACD. Informants considered that the SDSS was an improvement on previous methods for organizing LLIN distribution, IRS and RACD, and could be easily integrated into routine malaria and other vector-borne disease surveillance systems. Informants identified some challenges at the programme and field level, including the need for more skilled personnel to manage the SDSS, and more training to improve the effectiveness of SDSS implementation and use of hardware.

Conclusions: The SDSS was well accepted and informants expected its use to be extended to other malaria reporting districts and other vector-borne diseases. Challenges associated with efficient SDSS use included adequate skills and knowledge, access to training and support, and availability of hardware including computers and global positioning system receivers.

Keywords: Bhutan, Spatial decision support system, Long-lasting insecticidal nets, Key informants

Background

Bhutan has shown considerable success in controlling malaria, having achieved substantial reductions in malaria morbidity and mortality from 2670 cases and five deaths in 2004 to 42 cases and no deaths in 2014 [1]. Malaria elimination is now Bhutan's goal, with the aim to be malaria-free by the year 2016 [2, 3]. Malaria elimination needs a relentless focus on surveillance and response. In many other countries entering the pre-elimination phase, initial efforts have focussed on creating line listings of confirmed cases at the district level and case mapping by village, which constitutes an elementary form of malaria focus delineation [2]. However, as elimination

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activities intensify and the malaria incidence approaches zero, higher-resolution mapping at the household level may be required in residual areas of transmission. The need for modernized, high-resolution mapping to support the operational management of scaled-up interventions is increasingly being recognized [4].

Paper-based maps have been used for planning malaria interventions since the eradication efforts in the 1960s [5]. More recently, electronic geographic information systems (GIS), which permit input, storage, manipulation, and output of geographic information, have provided a powerful suite of tools for managing data in the context of the prevention and control of malaria. There is a plethora of GIS software packages available, with varying capacities for data processing, analysis and display. Spatial analysis in disease management and health planning is now well established [6–10]. Spatial decision support systems (SDSS) provide enhanced support for decision making and management, using data that have a geographical component [11]. A SDSS is generally based on a database housed within a GIS, with an interactive mapping interface. SDSS can contain modules for planning, monitoring and evaluating the delivery and coverage of interventions such as indoor residual spraying (IRS) and distribution of long-lasting insecticidal nets (LLINs) within target populations, and for mapping malaria surveillance data, including identifying and classifying active transmission foci and guiding targeted responses [10, 12–16] (Fig. 1). Such tools have been successfully used to support malaria elimination in a variety of countries [7, 13]. However, limited rigorous evaluation of these tools has been done. These tools require an investment in financial and human resources to develop and implement [17] and considerable effort to maintain. Whilst it appears intuitive that such systems will improve the efficiency of malaria elimination interventions through supporting more effective resource allocation decisions, SDSS uptake depends on establishing acceptability and utility.

The traditional surveillance system in Bhutan is based on passive reporting of cases and fever surveillance. In the traditional reporting system, the location of households with malaria is not available—data are recorded at the village level. By contrast, the SDSS maps cases at the household level and enables the spatial relation of the index case to other households to be mapped. This is essential for facilitating reactive case detection (RACD) in 1-km buffer zones, which is the main approach to containing transmission.

The aim of the present study was to develop and implement a SDSS based on open source GIS (Quantum GIS) to aid in the distribution of LLINs, carry out IRS and for RACD as part of the malaria elimination efforts of Bhutan. Additionally, this study aimed to determine the acceptability and utility of the SDSS for malaria elimination in Bhutan using informant interviews with those involved in the programme.

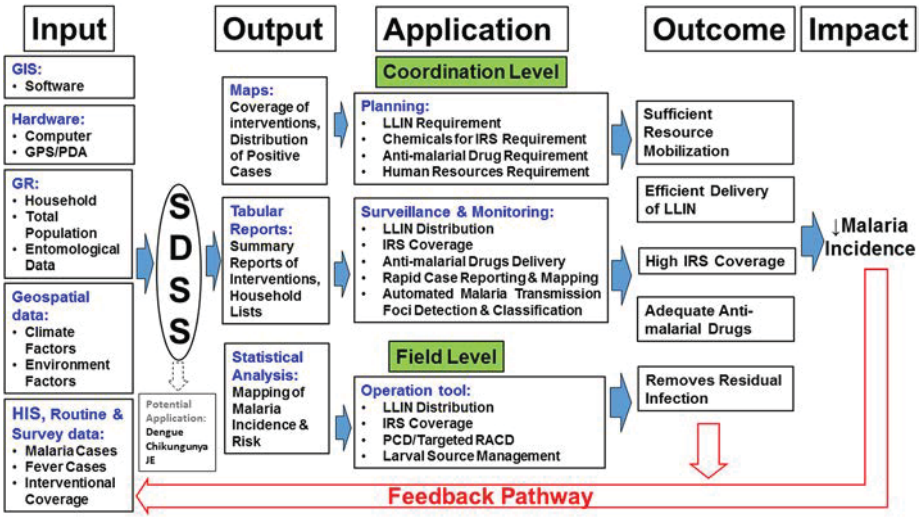

Fig. 1 Framework of spatial decision support system for malaria control and prevention with potential use in other vector borne diseases. (*GIS* geographical information system, *PDA* personnel digital assistant, *GPS* Global positioning system, *SDSS* spatial decision support system, *GR* geographic reconnaissance, *LLIN* long-lasting insecticidal net, *IRS* indoor residual spraying, *PCD* passive case detection, *RACD* active case detection, *JE* Japanese Encephalitis)

Methods

Study area

Malaria in Bhutan is reported in seven districts: Chukha, Dagana, Pemagatshel, Samdrup Jongkhar, Samtse, Sarpang, and Zhemgang [18, 19] (Fig. 2). These districts are located in the foothills of the Himalayas, bordering the Indian states of Assam and West Bengal, which report some of the highest numbers of malaria cases in India [20–23]. The climatic conditions in these districts are hot and humid during summer months with plenty of rainfall providing a suitable environment for vectors [18, 19].

Currently, focal IRS is routinely conducted in households in malaria-endemic districts of Bhutan every 6 months, using synthetic pyrethroid. This spraying is carried out prior to and immediately following the monsoon season, in March and September. LLINs are distributed by the Vector-borne Disease Control Programme (VDCP) of the Department of Public Health (DoPH) within the Ministry of Health (MoH) every 3–4 years. Malaria technicians at the respective health centres are responsible for planning and distribution of LLINs and coordinating IRS. They are assisted by sprayers who have been trained by the VDCP in carrying out IRS. Additionally, treatment is with artemisinin-based combination therapy (ACT) [24]. Elimination efforts are further augmented with interactive information, education and communication and behavioural change and communication strategies to enhance utilization of interventions.

Of the seven malaria-endemic districts of Bhutan, Samdrup Jongkhar and Sarpang Districts were selected for the current study because these districts persistently reported the highest incidence of malaria in Bhutan over the last 7 years [24]. Further, two sub-districts were selected from each district on the basis of them having the highest numbers of malaria cases in their respective districts. Jomotshangkha basic health unit (BHU) I caters to Langchenphug sub-district and Samdrupchoeling BHU I caters to Phuntshothang sub-district in Samdrup Jongkhar District. Chuzergang and Umling BHU II serve Chuzergang and Umling sub-districts in Sarpang District, respectively (Fig. 2).

Building the spatial decision support system

The free software QGIS was used as the GIS software platform for the development of the customized SDSS application. Microsoft Excel (Microsoft Corp, Redmond, WA, USA) software was used for additional integrated data management and analysis.

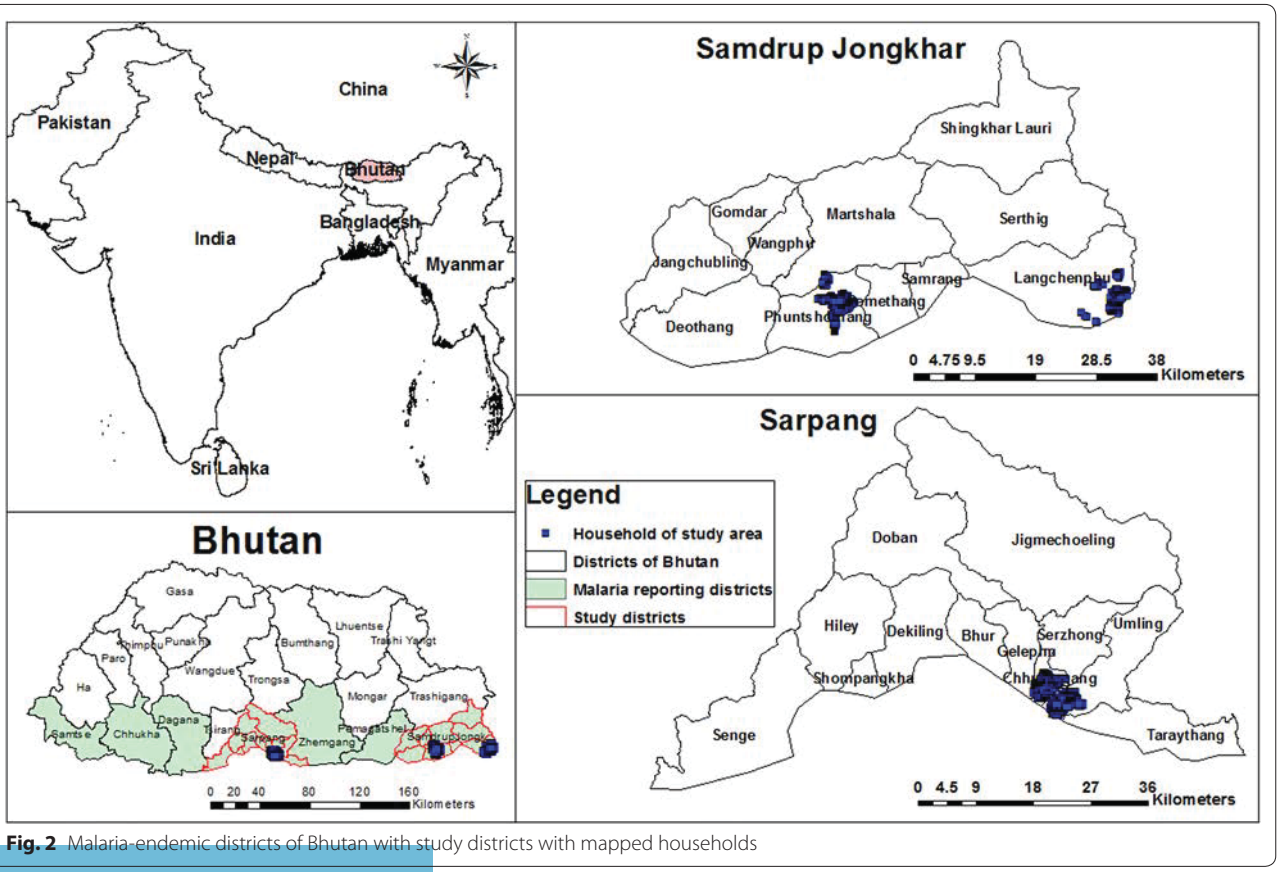

Fig. 2 Malaria-endemic districts of Bhutan with study districts with mapped households

Geographic reconnaissance (GR) of the households in the two sub-districts of Phuntshothang and Langchenphug in Samdrup Jongkhar was carried out in August–September 2013 with the aim of achieving complete enumeration and geo-referencing of households. Chuzergang and Umling sub-districts also had household map data available from previous smart-phone based field mapping operations (unpublished study). Information captured during GR and from existing surveys included a unique household identification number, name of the head of family, the type of household, numbers of rooms, total number of residents and number of children under 5 years old in each household. Two staff from the VDCP, Bhutan were trained on using handheld computer devices with an integrated global positioning system (GPS) (Trimble Juno) for carrying out mapping of the households (GR) in August 2013. These trained staff were further assisted by the malaria technicians of the respective health centres of Samdrupchoeling BHU I for Phuntshothang sub-district and Jomotshangkha BHU I for Langchenphug sub-districts in Samdrup Jongkhar district (Fig. 3).

Household geolocation (latitude and longitude) data were downloaded from the GPS and merged to create shapefiles in QGIS, which were used for analysis and creating cartographic outputs (Fig. 4).

After development of the SDSS, standard operating procedures (SOPs) were developed and 2 days of training in the use of the SDSS was provided to officials of the VDCP. These officials included the chief programme officer (CPO), deputy CPO, medical entomologist and information officer from the national VDCP, district malaria supervisor of Sarpang District and malaria technicians of Chuzergang and Umling BHU II. Following the initial introduction and training period, the programme officials and the malaria technicians operated the SDSS independently over a six-month period from June to November 2014.

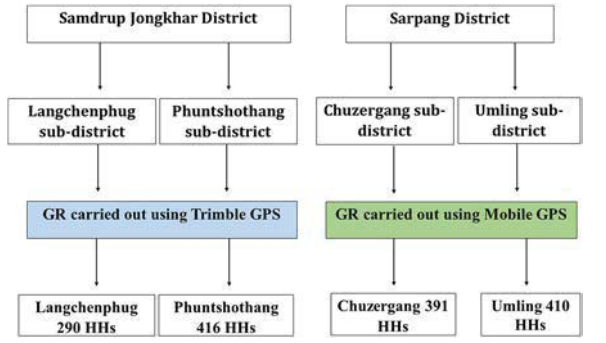

Fig. 3 Selection of districts and sub-districts for building spatial decision support system. (*GR* Geographic reconnaissance, *GPS* Global positioning system, *HHs* households)

Application of the SDSS for managing LLIN distribution and IRS

Intervention data were recorded in Microsoft Excel and uploaded into the SDSS, where they were linked to households using the unique household number so that coverage and service distribution could be monitored via a map interface (Fig. 4). Household information was extracted from the SDSS into Microsoft Excel and hardcopies were sent to district and field level staff conducting field activities (Figs. 5, 6).

One of the programme officials was trained in the use of GIS through aegis of Asia Pacific Malaria Elimination Network (APMEN) and WHO. He took the lead role with the extraction of hardcopy lists of households for planning, monitoring and implementation of LLIN distribution in December 2013 and IRS in April 2014.

Following these activities, a survey was carried out to assess the SDSS in June 2014. The mean number of LLINs per households was calculated and compared (using the t test) between the sub-districts that used the SDSS versus sub-districts that used routine data management methods. Similarly, the proportion of households covered during the routine IRS between the sub-districts was calculated. A value of $p \leq 0.05$ was considered significant.

Application of the SDSS for RACD

A module of the SDSS, developed for RACD, was implemented in all the study sub-districts (Fig. 7). In elimination settings, every case of malaria warrants active follow-up to identify any residual infection [25]. The existing guidelines of Bhutan require investigation of residual infections in the population residing within 1 km of an identified index case. A simple spatial query application was used for creating buffer zones of 1 km around households which reported malaria infections. After creating the buffer zone, a list of all the households within this zone was extracted from the SDSS and exported into hardcopy forms. Summary information of households within the buffer zone was used by the managers of the VDCP for planning activities. Additionally, managers at the VDCP and districts gave hardcopy lists of households within the buffer zone to malaria technicians, who carried out field activities.

During RACD, malaria technicians visited all households within the buffer zone as per the hardcopy list and conducted blood tests, either a spot rapid diagnostic test (RDT) or blood smear for microscopy, on all residents. In the event that *Plasmodium* parasites were detected, radical treatment with ACT was initiated immediately. Other preventive measures included checking the adequacy of LLINs for the households and reminding residents of the importance of regular use,

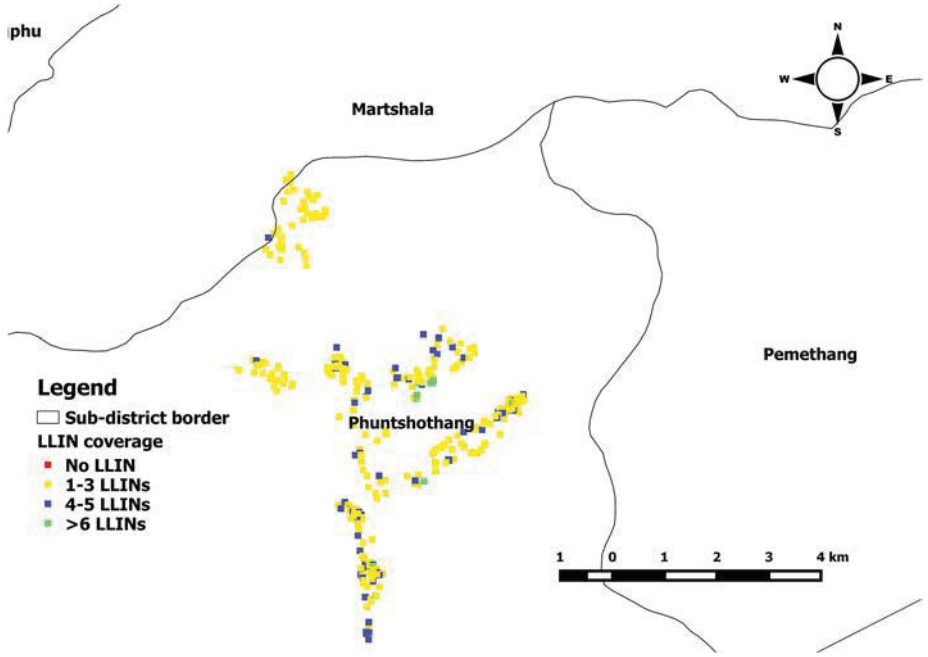

Fig. 4 Sample of output map for monitoring the coverage of long-lasting insecticidal net

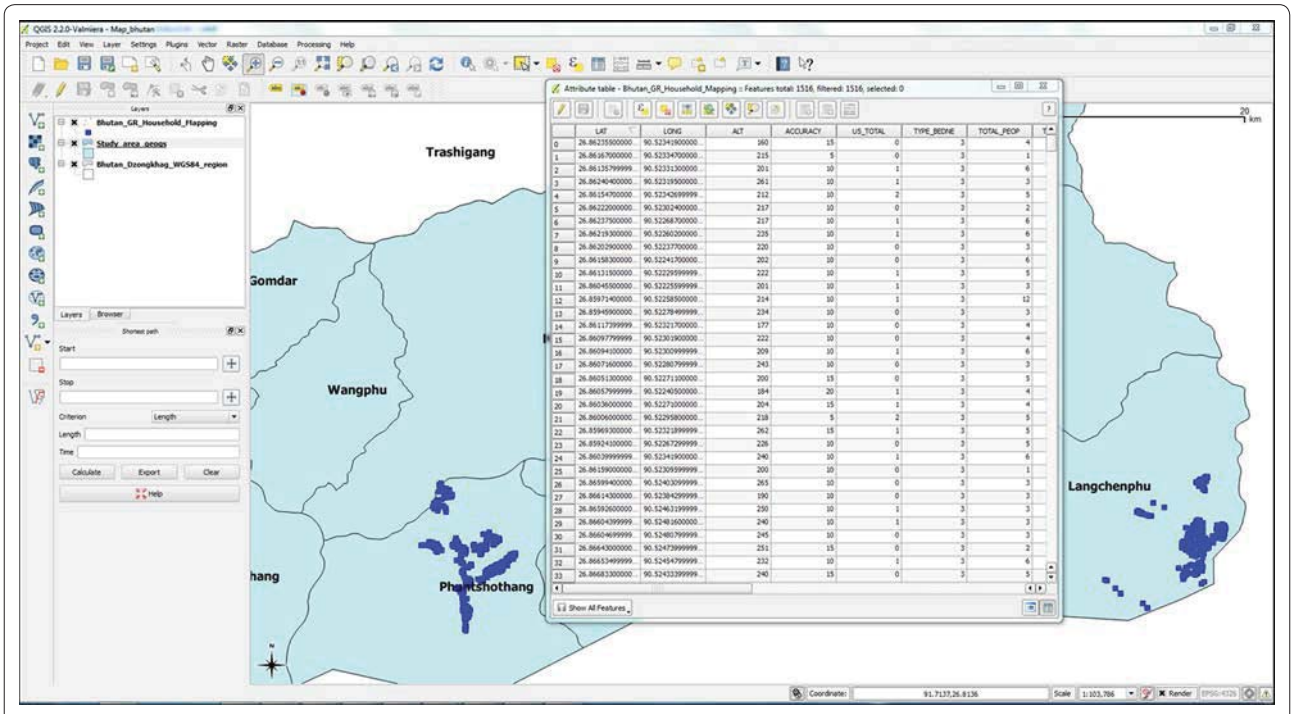

Fig. 5 Attribute table with households extracted from spatial decision support system

and environmental management to detect and remove (if possible) any stagnant water around the house. Additionally, health education on prevention of malaria was usually disseminated.

Evaluation of SDSS utility and acceptability

Informants for SDSS evaluation were selected for inclusion in the study on the basis of being involved in the implementation of the SDSS. At the national level, in

Lat	Long	GEOG	CHIWOG	HH Number	Target			Coverage		
					Total Pop	Under 5 Pop	Total Room	No of rooms IRS	No of rooms IRS not	Reasons for not doing IRS
26.8883	91.7053	Phuntshothang	Samdrupcholing	1602070006	7	0	8			
26.8869	91.7094	Phuntshothang	Samdrupcholing	1602070012	2	0	6			
26.8863	91.7076	Phuntshothang	Samdrupcholing	1602070009	7	0	10			
26.8865	91.7055	Phuntshothang	Samdrupcholing	1602060001	2	0	16			
26.885	91.7082	Phuntshothang	Samdrupcholing	1602070050	4	0	5			
26.8913	91.7118	Phuntshothang	Samdrupcholing	1602070045	7	1	9			
26.8916	91.7182	Phuntshothang	Samdrupcholing	1602070036	5	0	3			
26.8939	91.7102	Phuntshothang	Samdrupcholing	1602070042	7	0	4			
26.888	91.7051	Phuntshothang	Samdrupcholing	1602070005	3	4	2			
26.891	91.716	Phuntshothang	Samdrupcholing	1602070038	3	0	2			
26.8877	91.705	Phuntshothang	Samdrupcholing	1602070004	2	1	1			
26.8881	91.7153	Phuntshothang	Samdrupcholing	1602070028	4	1	3			
26.8836	91.709	Phuntshothang	Samdrupcholing	1602070054	12	0	13			
26.8835	91.709	Phuntshothang	Samdrupcholing	1602070001	12	1	15			
26.8858	91.7099	Phuntshothang	Samdrupcholing	1602070018	3	0	11			
26.8854	91.7099	Phuntshothang	Samdrupcholing	1602070019	10	1	20			
26.89	91.7171	Phuntshothang	Samdrupcholing	1602070032	8	0	8			
26.8918	91.7152	Phuntshothang	Samdrupcholing	1602070039	7	0	7			
26.8879	91.7112	Phuntshothang	Samdrupcholing	1602070024	4	0	4			

Fig. 6 Operational tool: sample of form extracted from spatial decision support system for carrying out indoor residual spraying. (*IRS* indoor residual spraying, *HH* household, *Lat* latitude, *Long* longitude, *Pop* population)

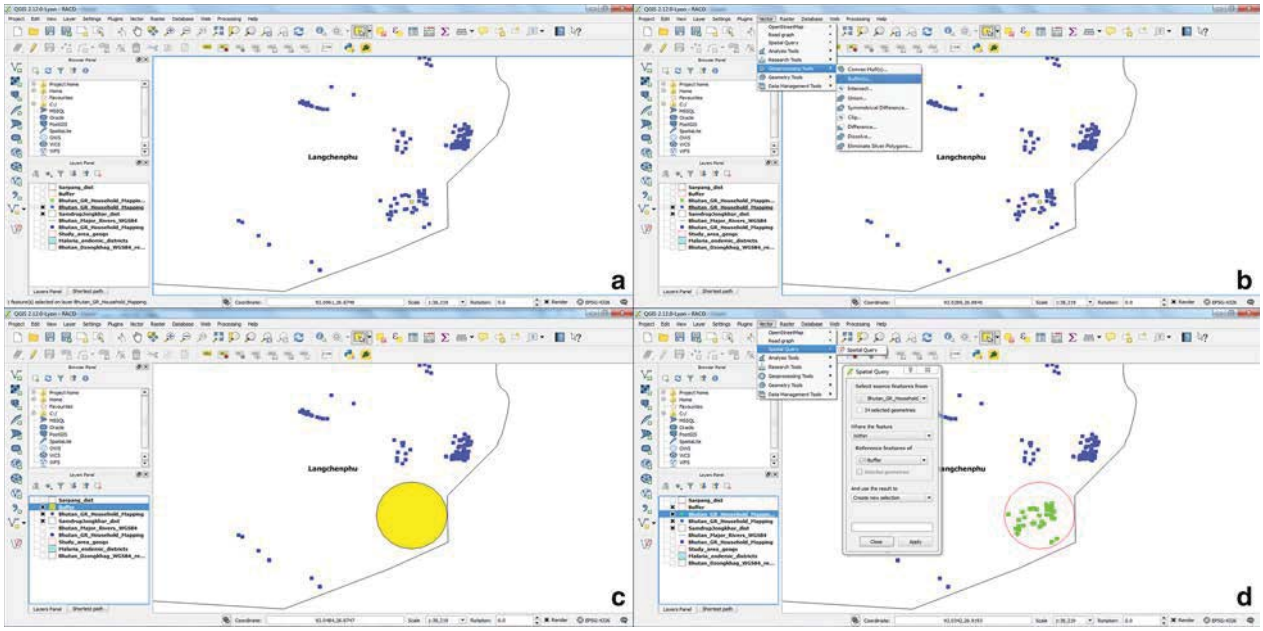

Fig. 7 Creation of buffer zone and extracting households that lie within 1-km radius of the index case for reactive case detection. **a** Selection of household that reported malaria; **b** steps involved in creation of buffer zone; **c** buffer zone is created with 1-km radius of the foci of infection; **d** enlisting households that lie within the buffer zone)

addition to the medical entomologist and information officer, two programme managers were interviewed. A district malaria supervisor and six malaria technicians from four health centres that catered to the study sub-districts were interviewed, giving a total of 11 informants. All interviews were conducted face to face. The semi-structured interviews lasted from 20–45 min. Open-ended questions were aimed at eliciting an informant's knowledge and experiences while implementing the SDSS and covered the acceptability and utility of the SDSS, and barriers to its use. Interviews were conducted in several languages (English, Dzongkha and Tshangla) and electronically recorded by the lead author (KW), and field notes were written to supplement the recordings. Interviews were transcribed by hand and were manually coded to examine emerging themes related to the research questions. The results (i.e., the emerging themes) were compared between national, district and fieldworker informants.

Ethical clearance

Ethical approval for this study was provided by the Research Ethics Board of Health (REBH), MoH, Royal Government of Bhutan (reference number: REBH/Approval/2013/014), the Human Research Ethics Committee of the University of Queensland (reference number: 2013000884) and the Human Ethics Committee of The Australian National University (Protocol No 2014/633). Verbal permission from local community leaders was sought prior to conducting the survey. Written informed consent was obtained from the head of each household or questionnaire respondent. Interviewer explained the general purpose, benefits and any risks of the survey to each respondent in his or her local language. Respondents had the right to refuse participation in the survey at any point. Confidentiality was maintained at all times during recording of the interviews.

Results

Spatial decision support system implementation

A total of 1502 households were georeferenced and mapped in the four study sub-districts in Samdrup Jongkhar and Sarpang, including 704 prospectively mapped in Samdrup Jongkhar and 798 previously mapped in Sarpang. The total population was 7165, including 640 children under 5 years and study households had a total of 5955 rooms (Table 1).

In Samdrup Jongkhar, Langchenphug sub-district was divided into seven villages and two settlements, while Phuntshothang sub-district was made up of ten villages. In Sarpang, Chuzergang sub-district was composed of ten villages and one school, and Umling sub-district had eight villages.

There were 1814 LLINs providing protection to 2967 people in the district where the SDSS was used (Samdrup Jongkhar) and 1677 LLINs provided to 2763 people in the district where the SDSS was not used (Sarpang), giving a total per person of 1.7 in both districts ($p = 0.95$) (Table 2).

A total of 7397 rooms were covered during the IRS in April 2014 covering a total of 8662 population (Table 3). The total rooms covered in the districts where the SDSS was used (Samdrup Jongkhar) was 4155 while in the districts where the SDSS was not used (Sarpang) was 3166. A total of 150 and 87 households (covering 413 and 234 people) were targeted for RACD in Samdrup Jongkhar and Sarpang districts, respectively, during the study (Table 4).

Key informants' perceptions of the SDSS

Benefits

Key informants identified a number of positive aspects of the SDSS as an information management system. The SDSS aided in maintaining electronic records which makes it helpful for decision making, planning, monitoring, and accountability. One programme manager observed that it could precipitate more accurate and timely decision-making at the regional and local levels:

Table 1 Summary of the households, total population, under five years and total rooms included in geographic reconnaissance in 2013

Districts	Sub-district	HH	Total population	Under-five population	Total rooms
Sarpang	Chuzergang	391	1673	158	1348
	Umling	409	2298	204	1663
Samdrup Jongkhar	Langchenphug	289	1182	103	1140
	Phuntshothang	415	2012	175	1804
Total		1504	7165	640	5955

HH households

Table 2 Summary statistics of the long-lasting insecticidal nets and population

Districts	Total pop.	LLIN	Average persons per LLIN	P value
Sarpang	2810	1677	1.7	0.95
Samdrup Jongkhar	2967	1814	1.7	
Total	5777	3491		

LLIN long-lasting insecticidal net

Table 3 Summary of indoor residual spraying coverage with population

Districts	Total pop.	Rooms covered in IRS
Sarpang	3276	3242
Samdrup Jongkhar	5386	4155
Total	8662	7397

Source: VDCP, Department of Public Health, Ministry of Bhutan

IRS indoor residual spraying

Table 4 Reactive case detection carried out in 2014 and 2015

Districts	Sub-districts	Index case	No HHs	Total population
Sarpang	Umling	1 *P. V*	30	64
	Chuzergang	2 *P. V*	57	170
Samdrup Jongkhar	Langchenphu	1 *P. V* and 1 *P. F*	150	413
	Phuntshothang	1 *P. V*	42	81
Total			279	728

Source: VDCP, Gelephu, Bhutan

P. V Plasmodium vivax, P.F Plasmodium falciparum, *HHs* households

"I think the SDSS is very useful especially for the programme to have a tool in place to make a prompt decision, make accurate decisions.... Secondly, after your training of the staff in the field, they also initiated decisions at their level".

(Informant 1, Programme official).

More specifically, due to its capacity to store information, the SDSS could be used to calculate the numbers of LLINs and chemicals required and for human resources and education. This aided planning for responses into the future and determining budgetary needs.

"Since we have the number of households, with numbers of rooms, in the SDSS, it will help in planning for the requirement of chemicals for IRS".

(Informant 4, Programme official).

"As we already have the total population of each household, we can calculate an accurate number of LLINs required for each village".

(Informant 4, Programme official).

"The SDSS will help us in estimating the distance of location of meeting areas from the health centre. ... if the distance is far we can organize the meeting area in the next village, which is a shorter distance. This helps in planning for health education".

(Informant 9, Fieldworker).

The SDSS was reported to make various control activities easier, such as for demarking the areas to be included in RACD around the foci of infection.

"Previously we did not know how many households to be included in RACD. The SDSS helps us to generate the list of households that are required for us to do RACD".

(Informant 5, District official).
"We can say which households are located near breeding sites. In the SDSS we can easily identify these features in the maps".

(Informant 5, District official).

Through its ability to store data, the SDSS was reported to assist in monitoring the adequacy of LLINs and coverage of IRS, thereby improving the accountability for work-related actions amongst the end users. Supervisors could easily monitor different activities carried out by malaria technicians using the SDSS (upward accountability). Additionally, some of the interviewed fieldworkers thought that the SDSS would make it easier for them to convince supervisors and politicians to prioritize malaria elimination activities by demonstrating the burden of disease and identifying priority actions (downward accountability).

"Use of the SDSS is very good because firstly, malaria control activities in Bhutan can be done through mapping.....We can map [control activities] so our immediate bosses or other officials in the programme and other people anywhere in Bhutan can see what we are doing in the field".

(Informant 6, Fieldworker).

"We can use the SDSS for budgeting and convincing the policy makers since we have the proof to show them that we have so many households".

(Informant 5, Programme official).

"After introduction of the SDSS, it is easy to follow patients in the field since we can pinpoint the exact location of the household of the patient".
(Informant 7, Fieldworker).

The SDSS was perceived to be cost effective and to provide information in a more timely fashion relative to routine methods for managing malaria elimination activities. In the routine method, malaria technicians visited each household every time the LLIN distribution was planned. They also visited households every 6 months for planning of IRS to record the number of rooms in each household to calculate the amount of chemicals (pyrethroid) and manpower required for carrying out IRS. This method was labour-intensive and costly since malaria technicians have to be paid. By contrast, the SDSS database contains all the necessary information: these data can be extracted easily to support planning, implementation, monitoring, and evaluation of LLINs and IRS without the need for six-monthly visits.

"In regards to cost, I think using the SDSS is cheaper. It is easier as well. When we use paper-based reporting, it consumes lots of time. The costs are incurred because we need to buy the paper, and then [pay for] printing. The reports are sent through the post, which delays the submission of reports".

(Informant 5, District official).

"In terms of cost, in the beginning I think the SDSS will be expensive because we need to buy hardware and software. But in the long run it will be cost effective because the data in the SDSS can be easily reused once the data are fitted into the software".

(Informant 1, Programme official).

Previously, reports were submitted either through post or electronically via fax, causing problems, including delays in submitting the reports to, and receiving feedback from, the national and district managers, when postal services were used. Submission of reports electronically via fax is also subject to constraints such as erratic electricity supplies and breakdown of fax machines. These challenges would be easily addressed through future refinement of the SDSS to incorporate web-based or mobile-phone reporting.

Informants reported that they did not feel it was a burden to use the SDSS in addition to the routine surveillance system. Some fieldworkers thought that they would gain new knowledge and skills from the SDSS which might assist in career advancement. In the rapidly changing world of information technology, the SDSS provided a new platform through which the fieldworkers could embrace the paradigm shift in information technology for delivery of services.

"I did not feel [using the SDSS] as a burden. It is added knowledge and it is helpful".
(Informant 8, Fieldworker).

Supervisors were not likely to see the SDSS as an additional burden for their fieldworkers.

"In my opinion the field workers did not feel it as a burden. Rather [they see it as] an additional tool [to help] them work. The SDSS helped them for planning and distribution of LLINs".

(Informant 4, Programme official).

Most of the informants stated that integration of the SDSS as part of the routine system for managing malaria elimination activities could be accomplished easily. The SDSS could also be used for surveillance and control activities in other vector-borne diseases, such as dengue, Chikungunya and Japanese encephalitis (JE). Vector mapping using the SDSS can be integrated into routine systems for vector-borne disease surveillance. The informants also recognized the potential of the SDSS for use in other public health programmes.

"We can [use the SDSS] for other vector borne diseases such as dengue. We can map the [mosquito] breeding places for each household, such as flower pots and other breeding sites near the houses".

(Informant 9, Fieldworker).

"The SDSS should not only be integrated into malaria and vector borne disease, it should be used for other diseases and other activities like rural water supply schemes (RWSS) to monitor the coverage and use of the RWSS. It can be used even for latrine coverage and construction".

(Informant 5, Programme official).

Challenges

The informants identified some difficulties with the SDSS. At the national level, one of the main challenges was the shortage of human resources with expertise in GIS and other relevant technical areas. In particular they identified the need for a technical officer.

"Even at the programme level we do not have an expert, specifically an expert in GIS. In the long run, I think we might have to look for one who can guide us".

(Informant 1, Programme official).

Most of the field-level informants were concerned that there was a lack of adequate knowledge and skills in implementing the SDSS in practice. This fieldworker summarized the situation:

"Firstly, we will require skills and knowledge. Without adequate skills and knowledge we cannot use the

SDSS efficiently. Secondly, we will need ideas on how to carry out the mapping. Other challenges include [availability of] equipment namely: GPS and computers".

(Informant 10, Fieldworker).

They reported that a week's additional training would be enough for them to use the SDSS efficiently.

"At the BHU level, I cannot create a buffer zone myself, but I was given the lists of households to be followed by the programme".

(Informant 7, Fieldworker).

"I would like to request to give us training. Even if not in a group, they can give training individually".

(Informant 6, Fieldworker).

However, a district official highlighted that fieldworkers need to use the SDSS regularly so as to maintain their skills.

"Once they are trained they need to use it regularly so that they learn how to use it".

(Informant 5, District official).

Another challenge was the need for more equipment including computers (laptops) and mobile phones with GPS.

"One of the problems in the past was not having a computer. We still do not have computers. Not having a GPS is another problem. There are no proper internet services".

(Informant 11, Fieldworker).

Fieldworkers also noted a lack of reliable internet services and the cost of using the internet.

"The internet is the problem … we cannot afford to pay".

(Informant 7, Fieldworker).

Other challenges include safety of the field workers deployed in the border areas.

"I think there is some risk while implementing it in border areas".

(Informant 8, Fieldworker).

Discussion

This paper presents the development and implementation of a SDSS in two of the seven malaria-reporting districts in Bhutan. LLIN coverage in the study area was one LLIN per 1.7 persons, which surpassed the WHO recommended ratio of one LLIN per two persons for malaria-endemic areas with low transmission [26]. Whilst coverage of LLIN was no different in the sub-districts that did and did not use the SDSS, a number of other benefits of SDSS use were identified through the key informant interviews.

The routine operations of the VDCP of Bhutan to visit and count houses before LLIN distribution is a form of detailed reconnaissance which is very rarely done in other malaria programmes prior to an intervention because it is time and resource intensive. However, this standard approach does not involve digital capture or detailed enumeration of households, and the SDSS was an advance on routine operations in these key aspects. Opportunities to incorporate geo-spatial data collection, using a digital data collection device with a GPS, into the routine activity of 'house-to-house reconnaissance' provided an opportunity to smoothly integrate the SDSS into the programme without a great deal of further effort or investment. Digital enumeration and incorporation of geo-referenced household data into the SDSS provides an opportunity to further utilize these data for essential components of malaria elimination, including management of operational data and high-resolution surveillance and targeted responses. Whilst costs were not determined for this pilot SDSS, research in Melanesia highlights predominant costs and resources for SDSS implementation are largely associated with specialized equipment and travel, particularly in relation to GR [17]. As demonstrated in this study, time and cost efficiencies can be achieved through implementing GR in conjunction with routine house-to-house or community level programme field activities.

Through the automated mapping of LLIN coverage, programme managers were able to monitor the progress and visualize the spatial distribution of coverage. The managers could provide feedback to the malaria technicians in the field on intervention coverage thereby ensuring adequate and uniform distribution. Similarly, monitoring and interactive communication on IRS coverage was also carried out using the SDSS [13].

While the focus of the malaria control phase within a malaria elimination programme is achieving population coverage with preventive methods and access to treatment, the defining aspects of malaria elimination programmes are: detection of all malaria cases, prevention of onward transmission, management of malaria foci, and management of importation of malaria parasites [27]. Creation of buffer zones of 1 km around households with cases ensured proper coverage as per the national policy. However, it was found that the buffer zone sometimes extended across international boundary, preventing malaria technicians from completing follow-up activities

since the area was outside their administrative jurisdiction. This highlights the importance of cross-border dialogue and co-operation, and collaborating control and preventive measures [28]. Secondly, it was difficult to include all the members of the households in RACD when carried out during the day because children would be in school while adults would be engaged in occupational activities, such as farming. Therefore, to achieve greater coverage of population, it would be better to carry out RACD in the evening or early morning.

It is also important to assess the effectiveness of the system in supporting continuous surveillance, which in the elimination context requires integration of spatially and temporally explicit data for entomological and epidemiological outcome indicators. This allows for calculation of disease incidence, and assessment of reductions in vector exposure and malaria burden resulting from implemented control measures [29].

The major challenges identified through informants were: (a) inadequate human resources at the programme level to manage and implement the SDSS; (b) the need for more training and expertise; (c) more hardware such as computers, laptops and GPS; and, (d) inadequate availability or access (due to cost) to internet services. However, it was thought that the SDSS could improve: (a) the timeliness of reporting; (b) the accuracy in carrying out different control and preventive measures; and, (c) the upward and downward accountability of different officials for their work-related activities or duties.

Using an electronic SDSS made it easy to identify households not covered by IRS, unlike in the routine method, where this can only be done by referring to paper-based records. A similar finding has been reported elsewhere [13].

The informants thought that the SDSS-assisted surveillance system would save resources in the long run. It was highlighted that the initial cost of setting up the SDSS through procurement of GPS machines, computers, and payments for fieldworkers while mapping would be high. A cost analysis study has shown that the greatest costs were for procuring equipment and travel [17]. However, the costs incurred by the standard (non-SDSS) approach in form of payments to the malaria technicians who visit households every 6 months and every 3–4 years for planning of IRS and LLINs, would be saved.

There was a unanimous perception among informants that the SDSS could be easily integrated to support control activities of other vector-borne diseases, such as dengue, chikungunya and JE, which were reported recently in some parts of Bhutan [30, 31], and for other public health programmes, including maternal and child health, nutrition, TB and HIV, annual household surveys, rural water supply schemes (RWSS) and coverage of latrines [32–34]. A web-based SDSS could support dissemination of routine surveillance and outbreak data in real time and enhance feedback from the national or district levels to fieldworkers on timely manner.

One of the main barriers to a web-based SDSS is the availability of reliable internet services in health centres located in the rural parts of Bhutan. However, plans to set up government to citizen (G2C) centres in all 205 sub-districts might provide a solution where internet services are erratic and limited [35].

Another theme that emerged was accountability of different activities carried out by malaria technicians. They stated that their activities could be easily monitored by the district and national level officials through the SDSS. Additionally, use of the SDSS could aid in convincing supervisors and managers to allocate necessary resources. The coverage of preventive activities, such as LLINs, can be mapped, providing powerful visual evidence of the work done in the field.

The overwhelming response from the informants was that they did not perceive use of the SDSS to be an additional burden. Instead they felt SDSS helped in streamlining their activities. Some of the fieldworkers perceived the SDSS as providing new knowledge and skills and, therefore, an opportunity for career advancement.

Finally, informants from the national level highlighted a lack of adequate and skilled technical personnel at the programme level, and informants from the field consistently expressed their concerns regarding the need to have training in order to enhance and improve skills. Given that the training that was provided was for 2 days and not all of the informants were trained, it is clear that more in-depth training over a longer time period is needed. Additional mechanisms such as the provision of remote support and technical assistance via web-based communication would also be of value with regard to building and sustaining operational capacity.

Even though the SDSS contained data on the total population, it was felt that there is a need to update the population data every year, since the population changes over time. However, updating existing information would not be as labour intensive as the routine method where all information needs to be collected repeatedly. Updating of household population could also simply be incorporated into a targeted response intervention package as an activity to ensure data in priority areas remain current.

There were subtle differences between the national, district and field workers on some of the themes that emerged through this study. For example, despite receiving positive feedback from the fieldworkers, national officials did not think that the SDSS could replace paper-based surveillance completely, but could enhance existing paper-based reporting. The national level informants

felt that mapping households using mobile phones or GPS would be easy but using advanced features of the SDSS, such as data analysis, would be problematic at field level. If the SDSS included web-based components, programme officials felt that SDSS would help them to keep track of all the activities that are being carried out at field and district levels. Even though the SDSS was piloted in Bhutan, the experience of Bhutan could be used by other countries embarking on malaria elimination by identifying the likely barriers and enablers. Similarly, SDSS could be deployed for other public health programmes, particularly other vector-borne diseases such as dengue, JE and Chikungunya.

This study was subject to a number of limitations; whilst there were small number of informants (11), all the relevant people in Bhutan were included. Secondly, the lead author (KW) was involved in training of officials and fieldworkers. Six months later, he returned to conduct the informant interviews. The interviewees might have emphasized the positive aspects of the SDSS on the basis of social desirability.

Conclusions

Open source GIS software such as QGIS can provide an accessible platform to develop an SDSS to support key malaria elimination activities such as planning and implementation of LLIN distribution, including monitoring the uniformity and adequacy of LLINs and carrying out IRS. Additionally, this approach can be used for RACD for residual infections in response to cases of malaria being identified. This study showed there was high acceptability of the SDSS as a system for operational data management and surveillance. It was perceived that the SDSS was a better tool than routine approaches to managing malaria activities, and could be easily integrated into the routine malaria, and other vector-borne diseases surveillance system. Barriers for using the SDSS efficiently were adequate skills and knowledge, access to training and support, and availability of hardware such as computers and GPS receivers.

Authors' contributions

KW and ACAC conceived the overall study. KW undertook fieldwork, statistical analysis and interpretation of results and drafted the manuscript. ACAC assisted in statistical analysis, interpretation of results and was involved in the critical revision of the manuscript. CB advised on the design and analysis of the informant interviews, and provided critical revision of the manuscript. MLG assisted in interpretation and revision of the manuscript. GCK and RN assisted in fieldwork planning and in revision of manuscripts. All authors read and approved the final manuscript.

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Competing interests

The authors declare that they have no competing interests.

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CHAPTER SEVEN
DISCUSSION AND CONCLUSION

Districts of Bhutan that report malaria lie in the foothills of the Himalayas, adjacent to India and share borders with the Indian states of Assam and West Bengal. Bhutan's pursuit of malaria elimination is likely to be impaired by the high intensity of malaria transmission in these states. Cross-border malaria is of interest to Bhutan since borders are porous with frequent movement of people in both directions, and in places people live in immediate proximity to the border. Cross-border dialogue between the ministries of health does happen, but without much action on the ground. To maintain elimination efforts in Bhutan post 2016, malaria control and prevention in India will play an important role to this end.

Malaria cases have dwindled in recent years as a result of intensified control and preventive measures namely universal coverage of LLINs and IRS biannually of the population residing in malaria endemic districts. This was made possible with the generous funding from the GFATM, the WHO and GoI. As Bhutan is pursuing malaria elimination in 2016, this thesis was undertaken as operational research studies to determine the preparedness of Bhutan for achieving this national goal. The summary of thesis finding has been outlined under respective heading in the subsequent sections.

7.1 Malaria trend

During the malaria pre-elimination phase in Bhutan (2006-2014), there was a decreasing trend in numbers of cases, apart from increases in 2009 and 2010. This also coincided with a reduction in mortality due to malaria. The declining trend corresponded to the mass distribution of LLINs in 2006. Other control and preventive measures, and diagnostic methods, did not change during this period (e.g., mass distribution of LLINs was supplemented with regular IRS every six months), suggesting the delivery of LLINs was

the main factor explaining the decline. The impact of LLINs on reducing malaria incidence has been reported in other studies [37-40]. The resurgence of malaria in 2009 and 2010 could be due to waning effects of the insecticide after three years of use. A second round of mass LLIN distribution occurred in 2010. The decrease in malaria cases was maintained once new LLINs were distributed at regular intervals of three years, in 2010 and 2013. Our finding support the WHO recommendation of at least 20 standard washes of LLINs under laboratory conditions and 3 years of recommended use under field conditions [41].

7.2 Imported malaria

There has been a significant shift in the malaria burden in Bhutan from local to imported cases. Similar patterns whereby imported malaria exceeds the number of local cases has been reported by other countries pursuing malaria elimination [42-44]. The main source of imported malaria in Bhutan was from expatriate workers employed on hydro-electric projects in Wandue Phodrang and Trongsa districts in 2013 and 2014. Interestingly, numbers of cases amongst daily visitors reduced significantly in the last two years as compared to previous years. This could have been due to reduced prevalence as a result of improved control and preventive measures, and better health care services on the Indian side of the border. Whilst there have been reports of declining numbers of malaria cases in India in recent years, albeit a slower decline than in other countries in the region [45], neither of these scenarios could be substantiated in this research, particularly in the neighboring states of India.

The greatest threat to successful elimination of malaria in Bhutan is the continued risk of importation of malaria, particularly from India and other nearby countries. The two Indian states of Assam and West Bengal report the highest malaria burden in India [18, 19, 46-48]. The areas adjoining the international border are forested and are inhabited by

indigenous people with poor access to health facilities and services. These areas are subjected to ethnic violence, which impedes the delivery of health services [49]. A strategy to address cross-border malaria with India is crucial to maintain the gains that have been achieved by Bhutan so far. Migrants entering and overnighting in Bhutan usually undergo blood examination for malaria parasites. However, daily visitors do not undergo such a screening process, posing a significant risk of onward transmission to the local population [50]. Despite the declining number of cases among daily visitors, research and novel approaches are still required to address malaria importation by daily visitors from India to Bhutan. Additionally, attention needs to be paid to the risk of introduction of parasites by Bhutanese residents travelling through the Indian states of Assam and West Bengal, which provide the only road access between different areas in southern Bhutan. No prophylaxis is offered to people who travel through India to reach other areas in southern Bhutan as a rule.

During the period 2006-2014 in Bhutan, for both *P. falciparum* and *P. vivax* infections, males were infected more frequently than females. Similarly, people in the age group of 20-39 years were infected more frequently than other age groups. Young adult males are more likely to engage in outdoor occupations that expose them to biting mosquitoes. Traditionally, female Bhutanese stays indoors more and perform household chores, thereby benefiting from IRS and LLINs. The traditional female dress, which covers most of the body, might also provide protection against bites from mosquitoes. Similar findings, that women are better protected than men, have been reported by other studies [51-53].

7.3 The costs of intensified interventions in pre-elimination stage

Increased funding greatly enhanced the scale-up of prevention and control strategies through the provision of ACT (artemether-lumefantrine), LLINs, and IRS. International

donors, including the GFATM, WHO and GoI, were the major source of funding of malaria control and preventive measures during the pre-elimination phase. Bhutan received major funding from the GFATM in rounds 4 (USD 1·3 million), 7 (USD 1·6 million) and from the Global Fund Transitional Funding Mechanism (USD 0·8 million) [15]. The average international donor support for malaria control worldwide to malaria-endemic countries was USD 1·86 per person per year [54]. The corresponding figure for Bhutan was USD 2·4 per person per year for the population living at risk of malaria [55]. Bhutan's local funding is amongst the lowest in the WHO SEAR (South-East Asia Region) [56, 57]. This highlights Bhutan's increasing dependence on external funding.

Most of the international donor funds were used for procuring LLINs, drugs, RDTs and equipment such as microscopy and IRS spray pumps. The overall cost for procuring LLINs had been decreasing over the years, possibly due to the increased demand of LLINs by the countries scaling up malaria control or embarking on malaria elimination, creating lower unit costs. During the mass distribution of LLINs in 2006, an average of one LLIN was provided per 1.44 people, increasing slightly to 1·45 and 1·51 people in 2010 and 2013, respectively. These figures are better than the WHO recommended ratio of one LLIN per two persons for malaria endemic areas with low transmission [58].

In event of reduced donor funding, the RGoB needs to explore the possibility of public-private partnerships for cost sharing as well as social marking so that universal coverage of LLINs can be maintained in the malaria endemic districts post elimination.

7.4 Long-lasting insecticidal net coverage and prevalence of asymptomatic carriage

The cross-sectional study described in Chapter Five found a very high coverage of LLINs in two malaria-endemic districts of Bhutan. The VDCP strategy of distributing free LLINs to achieve a target of universal coverage in the malaria endemic districts of Bhutan

appears to have worked well. High coverage was complemented with sleeping regularly (93.9%) under LLINs, but with the reported percentage dropping during the winter months. The decrease in overall malaria cases in Bhutan is likely to have been as a result of high coverage and regular use of LLINs [59-62].

Asymptomatic carriage is indicative of partial immunity to malaria, with a low level of *Plasmodium* parasites (asexual or gametocyte stages), being detectable in the blood without the individual being ill. Children frequently challenged with *Plasmodium* species acquire immunity resulting in fewer clinical infections of malaria and less severe presentation with increased age [63]. This research found no asymptomatic cases in malaria elimination districts. This is likely to be indicative of low levels (or absence) of circulation of malaria parasites in the study population. However, the sensitivity of the RDTs in low-transmission settings with low parasite densities are low [64-66]. It is worth noting that targeting asymptomatic carriers is critical as countries embark on elimination because these carriers harbor the parasites for transmission from one season to the next [67-69]. This carriers can introduce parasites into the community with low acquired immunity resulting in resurgence and outbreaks [70].

7.5 Spatial decision support system for Bhutan

Spatial variation in the risk of malaria has been well established [23, 71]. Malaria in Bhutan conforms with observed patterns elsewhere, with clusters of higher transmission communities in different sub-districts [9]. A SDSS approach have many advantages over the routine surveillance system used in Bhutan in terms of increased efficiency in deployment of control measures [72]. A detailed understanding of the local micro-epidemiological situation within target areas is desirable for effective targeting of preventive measures [68, 73, 74]. Additionally, through the generation of maps, SDSS

provides a platform for monitoring the coverage of preventive measures including LLINs and IRS [75].

A SDSS was developed and implemented in four sub-districts of Bhutan along the Indian border. Following development of the SDSS, evaluation of LLIN coverage in the study areas showed that there was no difference in the coverage of LLINs in the sub-districts that used the SDSS to distribute LLINs compared to sub-districts that used routine methods, both achieving one LLIN per 1.7 persons. However, benefits of the SDSS were evident in terms of perceptions among a range of health personnel of greater ease of carrying out preventive and control measures with the support of the SDSS. Additionally, the geographical reconnaissance approach, and establishment of a geo-referenced database of the enumerated population that can be regularly updated, will have future benefits for the national malaria elimination programme because the routine approach involved enumeration of the population at an aggregate (household) level during each intervention round. The mapping of households with detailed information aided in calculating requirements for chemicals for IRS, LLINs and human resources [72, 75, 76]. The SDSS was well accepted by both the national program officials and the field workers. These findings were supported by similar findings in another setting [75]. Additional reported advantages included that the SDSS could improve: (a) the timeliness of malaria case reporting; (b) the accuracy in carrying out different control and preventive measures; and (c) the upward and downward accountability of public officials for their work-related activities or duties. Additionally, there were no perceived contradictions between the use of SDSS and existing guidelines.

The major challenges identified for SDSS implementation were: (a) inadequate human resources at the program level to manage and implement the SDSS; (b) and the need for more training and expertise; (c) the need for more hardware such as computers, laptops and GPS; and (d) inadequate availability or access (due to cost) to internet services.

RACD plays an important role in malaria elimination efforts in many countries [77-79]. The surveillance-response module of the SDSS was primarily aimed at addressing the challenges of completeness of geographical coverage of RACD activities in transmission hotspots [80] through creating buffers around the index case and extracting the lists of households in the buffer zone, which is then used by field workers to conduct fever screening. Enhanced capturing of cases when carrying out RACD in 1 Km radius around an index case was also reported in Swaziland [81]. As in the study in Swaziland, creating a buffer of 1 Km radius led to operational challenges such as inclusion of a large number of households in RACD interventions and the inclusion of areas that were located across the international boundary (due to some index cases being in houses within 1 Km of the border), preventing malaria technicians from completing follow up activities since the area was outside their administrative jurisdiction [81]. This challenge can be addressed through cross-border collaborative efforts such as information sharing and synchronization of the control and preventive measures across the border.

A SDSS-assisted surveillance system is likely to save resources in the long run. In our study, national officials expressed that the initial cost of setting up the SDSS through procurement of GPS machines, computers, and payments for field workers while geo-coding of households would be high. A cost analysis study of an SDSS in Solomon Islands has shown that the greatest costs were for procuring equipment and travel of the field workers [82]. However, in the case of Bhutan, the costs incurred by the standard (non-SDSS) approach in form of payments to the malaria technicians who visit households every six months and every 3-4 years for planning of IRS and LLINs, would be saved.

A SDSS can offer the potential for integration to support control activities of other vector borne diseases such as dengue, chikungunya and Japanese encephalitis (JE), which were reported recently in some parts of Bhutan [83, 84], and for other public health

programmes including maternal and child health, nutrition, tuberculosis (TB) and HIV, annual health household surveys, rural water supply schemes (RWSS) and coverage of latrines [85-87]. Operational research is required to establish the benefits and optimal approaches to integration of information management with other programmes using the SDSS approach.

A web-based SDSS could support dissemination of routine surveillance and outbreak data in real time and enhance feedback from the national or district levels to field workers in a timely manner. However, a major barrier to a web-based SDSS is the availability of a reliable internet service in the health centers located in the rural parts of Bhutan. Plans to set up government to citizen (G2C) centers in all 205 sub-districts might provide a solution where internet services are erratic and limited.

An advantage of visiting villages using the routine approach for line listing of the households (as opposed to the SDSS, where enumeration is done once, at the start of the programme) was the opportunities to meet people, providing an avenue to provide health education. The malaria technicians and VDCP officials thought that health education played an important role in reduction of malaria cases in Bhutan, and the existing literature supports that the repeated delivery of health education such as messaging that sleeping under LLINs and removing mosquito breeding sites is effective in lowering malaria-associated mortality and morbidity [88-90]. Other benefits of household visits included enabling the field worker to observe the use and care of LLINs, and environmental management, including keeping surroundings clean and removable of any mosquito breeding sites.

The findings from this pilot study showed that the SDSS offers an alternative tool for managing operational data to inform malaria elimination and preventive activities. This suggests that a similar SDSS-based approach could be used by other countries embarking

on malaria elimination for addressing the management needs of intensified surveillance and control activities.

Limitations

There are number of limitations in the studies encompassed in this thesis. These limitations have been outlined in each of the research chapters (Chapters Four to Six). Some specific limitations that require further elaboration include:

1. LLINs ownership and use by HH were based on self-report without verification in Chapter Five. Secondly, the respondents may have over-reported net use, or under-reported the use of LLINs for alternate purposes, on the basis of social desirability, especially given that the interview was conducted by the malaria technicians of the health centers of the catchment area.
2. In terms of using RDTs for malaria diagnosis, while the sensitivity and specificity of the RDT are reported to be high [64], reduced sensitivity might occur with low parasite densities and exposure of the RDT to extreme temperatures [65, 91-93]. Asymptomatic carriers in low intensity malaria may require advance testing methods for detection [94].
3. A small number of informants (11) participated in the qualitative studies evaluating SDSS acceptability and user friendliness (Chapter Six), although all relevant people in Bhutan were included. Secondly, the lead author (KW) was involved in training of officials and fieldworkers. Six months later, he returned to conduct the informant interviews. The interviewees might have emphasized the positive aspects of the SDSS on the basis of social desirability.
4. The cost calculations in Chapter Four did not include the cost of expired drugs and RDTs, nor the cost of training malaria technicians or quality assurance programs. The treatment of malaria and malaria associated complications is provided by physicians and other relevant health workers; the cost of treatment

providers was not included in the study due to difficulties in calculating the proportion of their time involved in providing treatments.

Conclusion

In conclusion, evidence was present that Bhutan is on track to achieve elimination by 2016; there was a significant reduction in local malaria cases during the study period; low transmission intensity was determined because no asymptomatic carriers were detected in the study communities in two endemic districts of the country; and LLIN coverage was high with regular use throughout the year (albeit with a slight reduction during winter). Despite the significant overall reduction in malaria burden, the proportion of malaria contributed by foreign nationals is on the rise. In 2014, roughly half of the cases were amongst expatriate laborers from India working in hydro projects in Bhutan, and foreign national daily visitors. This highlights the risk of cross-border malaria and importation of malaria from India. Given the long and porous border between India and Bhutan, cross-border collaboration and synchronizing control and preventive activities are of utmost importance. The malaria elimination programme is predominantly funded by international donor, which is not sustainable in the longer term. There is an urgent need to explore strategies to ensure sustainable funding for preventive and control measures following elimination in 2016. Current provision of LLINs and IRS need to be continued until malaria in the bordering states of India is significantly reduced. Therefore, continued investment will be required to procure LLINs and continue IRS every six months. Possible ways forward are strategies to initiate public-private partnership though cost sharing and social marketing of LLINs to maintain universal coverage of at-risk populations.

A major challenge in Bhutan and other malaria-eliminating countries is the optimal use of operational data to plan front-line interventions and surveillance-response. Open-

source GIS software such as QGIS can provide an accessible platform to develop an SDSS to support key malaria elimination activities such as planning and implementation of LLIN distribution, including monitoring the uniformity and adequacy of LLINs, and for managing RACD. There was high acceptability of the SDSS as a system for operational data management and surveillance. It was perceived that the SDSS was a better tool than routine approaches to organizing malaria activities, and could be easily integrated into the routine surveillance systems for malaria and other vector-borne diseases. Major barriers for using the SDSS efficiently were adequate skills and knowledge and availability of hardware such as computers and GPS receivers. The SDSS approach might provide a platform for integration of malaria elimination operations with the control of other vector-borne diseases and other important public health programmes such as maternal and child health (MCH), rural water supply and HIV/TB control.

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APPENDIX 1 STATEMENT OF AUTHORS' CONTRIBUTIONS TO ARTICLES

1. Wangdi K, Gatton ML, Kelly GC, Clements AC: **Cross-border malaria: a major obstacle for malaria elimination.** *Adv Parasitol* 2015, **89:**79-107.

Contributions

KW and ACAC conceived the idea for the review. KW did the literature review and wrote the review. ACAC provided substantial input in the form of critical reviewing. MLG and GCK contributed by revision of the manuscript. All authors took part in the review, preparation and final approval of the report.

Name	**Contribution**
Kinley Wangdi (KW)	80%
Michelle L Gatton (MLG)	5%
Gerard C Kelly (GKL)	5%
Archie CA Clements (ACAC)	10%

2. Wangdi K, Gatton ML, Kelly GC, Banwell C, Das V, Clements AC: **Malaria elimination in India and region implications.** *Lancet Infect Dis* 2016, 4:e336-343.

Contributions

KW and ACAC conceived the idea for the review. KW did the literature review and wrote the review. ACAC provided substantial input in the form of critical reviewing. MLG, CB and GCK contributed by revision of the manuscript. All authors took part in the review, preparation and final approval of the report.

Name	Contribution
Kinley Wangdi (KW)	75%
Michelle L Gatton (MLG)	5%
Cathy Banwell (CB)	5%
Gerard C Kelly (GKL)	3%
Vas Dev	2%
Archie CA Clements (ACAC)	10%

3. Wangdi K, Banwell C, Gatton ML, Kelly GC, Namgay R, Clements AC: **Malaria burden and costs of intensified control in Bhutan, 2006-14: an observational study and situation analysis.** *Lancet Glob Health* 2016, 4:e336-343.

Contributions

KW and ACAC conceived the study. KW did data extraction, statistical analysis, interpreted the results, and drafted the report. ACAC assisted in statistical analysis and interpretation of results and was involved in the critical revision of the report. CB, MLG, GCK, and RN assisted in interpretation and revision of the report.

Name	Contribution
Kinley Wangdi (KW)	72%
Cathy Banwell (CB)	5%
Michelle L Gatton (MLG)	5%
Gerard C Kelly (GKL)	5%
Rinzin Namgay (RN)	3%

Archie CA Clements (ACAC)	10%

4. Wangdi K, Gatton M, Kelly G, Clements A: **Prevalence of asymptomatic malaria and bed net ownership and use in Bhutan, 2013: a country earmarked for malaria elimination.** *Malar J* 2014, **13:**352.

Contributions

KW and ACAC conceived the study. KW undertook field work, statistical analysis and interpretation of results and drafted the manuscript. ACAC assisted in statistical analysis, interpretation of results and was involved in the critical revision of the manuscript. MLG assisted in interpretation and revision of the manuscript. GCK assisted in field work planning and in revision of manuscripts. All authors read and approved the final manuscript.

Name	**Contribution**
Kinley Wangdi (KW)	80%
Michelle L Gatton (MLG)	5%
Gerard C Kelly (GKL)	5%
Archie CA Clements (ACAC)	10%

5. Wangdi K, Banwell C, Gatton ML, Kelly GC, Namgay R, Clements AC: **Development and evaluation of a spatial decision support system for malaria elimination in Bhutan.** *Malar J* 2016, **15:**180.

Contributions

KW and ACAC conceived the overall study. KW undertook fieldwork, statistical analysis and interpretation of results and drafted the manuscript. ACAC assisted in statistical analysis, interpretation of results and was involved in the critical revision of the manuscript. CB advised on the design and analysis of the informant interviews, and provided critical revision of the manuscript. MLG assisted in interpretation and revision of the manuscript. GCK and RN assisted in fieldwork planning and in revision of manuscripts. All authors read and approved the final manuscript.

Name	**Contribution**
Kinley Wangdi (KW)	70%
Cathy Banwell (CB)	8%
Michelle L Gatton (MLG)	5%
Gerard C Kelly (GKL)	7%
Rinzin Namgay (RN)	2%
Archie CA Clements (ACAC)	8%

APPENDIX 2 SAMPLES OF QUESTIONNAIRE

Questionnaire (Annexure 1)

Code of the interviewer								
Date			2011	Time			AM/PM	
Household number								
Village name								
Geog name								
District								
Household members	Children < 10years							
	Male >10 years							
	Female >10 years							
No. of mosquito nests	LLINs							
	Other types of bed nets							

Questions on socio-demographic

1) Are you the head of household?
   - ⓪No ☐
   - ① Yes ☐
   - ②Others (specify)……
2) Age of respondents ☐☐yrs
3) Gender.
   - ①Male ☐
   - ②Female ☐
4) Number of family members in households: □□
5) List of family members.

SL No	Age	Gender
1.		
2.		
3.		
4.		
5.		
6.		
7.		
8.		
9.		
10.		
11.		

6) Marital status.
   - ①Married ☐
   - ②Single☐
   - ③Divorced ☐
   - ④Separated ☐
7) Education (highest level).
   - ①None ☐

②Non- formal education ☐
③Primary ☐
④High school ☐
⑤College and above ☐
⑥Others (specify)……..

8) Occupation:
①Farmer ☐
②Housewife☐
③Shopkeeper ☐
④Civil servant ☐
⑤Armed forced ☐
⑥Others (specify)…….

9) Income of household per month.
①Less than Nu.1500 ☐
②Less than Nu.3000 ☐
③Nu.3001-Nu.5000 ☐
④Nu. 5001- Nu.10000 ☐
⑤Above Nu.10000 ☐

10) Types of house.
①Hut ☐
②Wood and mud ☐
③Stone and wood ☐
④Bricks and cement ☐
⑤Others (specify)……..

11) How far is the nearest health center from your home?
①Less than one hour walking distance ☐
②One to three hour walking distance ☐
③More than three hour walking distance ☐

12. Do you own any of the following items?
①Television ☐
②Refrigerator ☐
③Rice cooker ☐
④Curry cooker ☐
⑤Others (specify)…….

13. Have you travelled in last eight weeks?
①Yes ☐
②No☐

14. Have you used LLINs/bed nets last night?
①Yes ☐
②No ☐

Knowledge on malaria

1) What are the three most important illnesses in the village?
①…….
②……..
③……...

2) Have you ever heard about malaria?
①Yes ☐ (go to question 2)
⓪No ☐

3) How did you hear about malaria (multiple responses)
①T.V ☐

②Radio ☐
③Health worker ☐
④Billboards, newspapers ☐
⑤Malaria patients ☐
⑥VHW ☐
⑦Village leaders and elders ☐
⑧Local healers ☐
⑨Others (specify)……..

4) What would be your choice of media for information on malaria messages (which media is best for understanding malaria)?
①T.V ☐
②Radio ☐
③Billboards ☐
④Health workers ☐
⑤News papers ☐
⑥Pamphlets ☐
⑦Others (specify)…….

5) What causes malaria?
①Bite of mosquitoes ☐
②Eating stale food ☐
③Swimming in the river ☐
④Evil spirits ☐
⑤Working long duration in sun ☐
⑥Other (specify)……..

6) Where do mosquitoes breed?
①Dirty stagnant water ☐
②Clean stagnant water ☐
③Dirty flowing water ☐
④Clean flowing water ☐
⑤Do not know ☐

7) Where do mosquitoes rest during the day time?
①Dark corners of the house ☐
②Bushes ☐
③Paddy fields ☐
④Don't know ☐
⑤Others (specify)……

8) What are the symptoms of malaria? (multiple responses)
①Fever ☐
②Chills and rigor ☐
③Headache ☐
④Nausea and vomiting ☐
⑤Anemia ☐
⑥Loss of consciousness ☐

9) What are the reasons for delay in seeking help from health centers?
①Gets well without serious outcome ☐
②Local healers usually cure this type of illness ☐
③Health center is far away ☐
④Health workers are not co-operative ☐
⑤Others (specify)…….

10) How do you prevent yourself from getting malaria? (multiple responses)
①Sleep under bed nets ☐
②Using mosquito sprays ☐

③Burning coils ☐
④Personal hygiene ☐
⑤Making smoke (burning *sang*) ☐
⑥Others (specify)……..

11) Who is the most likely to get malaria?
①Mothers ☐
②Fathers ☐
③Children under 5 years ☐
④Other children ☐
⑤Grandmothers ☐
⑥Grandfathers ☐
⑦Guests ☐

Attitude on malaria

SL. No	Item	Scale				
		Strongly disagree	Disagree	Neutral	Agree	Strongly agree
1	Sleeping under bed nets can prevent mosquitoes.	1	2	3	4	5
2	Malaria is a serious disease.	1	2	3	4	5
3	Malaria is preventable disease.	1	2	3	4	5
4	Removing stagnant water in the surrounding can prevent malaria.	1	2	3	4	5
5	Keeping the surrounding clean can prevent malaria.	1	2	3	4	5
6	One does not need to get help from health centers if one gets sick from malaria.	5	4	3	2	1
7	Malaria cannot kill even if no treatment is taken.	5	4	3	2	1
8	Torn bed nets or LLINs are as effective as nets without tear or holes.	5	4	3	2	1
9	One cannot get malaria during the winters and rainy seasons.	5	4	3	2	1
10	One need not use bed nets or LLINs while sleeping outside or in the fields.	5	4	3	2	1

Practices

1) Do you use mosquito nets all year round, regularly?
①Yes ☐
⓪No ☐
2) If no, when do you stop using it?
①Summer months ☐
②Winter months ☐
③Others (specify)……
3) The reasons for not using regularly are (multiple responses)
①Mosquito nets are not enough ☐
②It is too hot to use mosquito nets ☐

③The rooms are small ☐
④The size of the mosquito nets are small ☐
⑤Others (specify)……..

4) Do you use mosquito nets or LLINs when sleeping outside or in the fields?
①Yes ☐ (ask question number 6)
⓪No ☐ (skip to question number 5)

5) What are the reasons for not sleeping under the LLINs or bed nets?(multiple response)
①There are no enough bed nets ☐
②It is hot ☐
③There are no mosquitoes ☐
④ Not convenient to use ☐
⑤Others (specify)……

6) Have you ever impregnated other types of bed nets within last six months
①Yes ☐
⓪No ☐

7) Have your house been sprayed in last six months?
①Yes ☐
⓪No ☐

8) Other methods of preventing malaria (multiple responses)
①Burn mosquito coils ☐
②Use repellents lotions ☐
③Burn *sang* (local incense) ☐
④Wear long sleeve cloths ☐
⑤Others (specify)……

9) How long would you seek help if anyone gets sick in your house?
①Within 24 hours ☐
②2-3 days ☐
③> 3 days ☐

10) Who is most likely to sleep under the bed nets?
①Mother ☐
②Father ☐
③Children under 5 years ☐
④Other children ☐
⑤Grandmother ☐
⑥Grandmother ☐
⑦Guests ☐

Ownership

1) Can you show me the nets?

SL. No	Types of nets	Conditions			
		No holes	Holes < 3 cm	Holes >3 cm	Torn beyond repair
1.					
2.					
3.					
4.					
5.					
6.					
7.					
8.					

2) How many times did you wash the LLINs or other types of bed nets after treatments?
   ①Six months after the treatments or after issue of LLINs ☐
   ②7 to 8 months after the treatment or LLINs ☐
   ③More than 9 months ☐
   ④Never ☐
3) What would you do if the bed nets get torn?
   ①Sleep without bed nets ☐
   ②Repair the bed nets ☐
   ③Buy a new one ☐
   ④Do not know ☐
4) Where do you keep the LLINs or bed nets during the day time?
   ①Keep hanging where it is being used at night time ☐
   ②Keep in the safe place such as cardboard or box ☐
   ③Keep at other place (specify)…….
5) Have you used LLINs or bed nets for any other purposes?
   ①Yes (ask questions 6 and 7) ☐
   ⓪No ☐
6) If yes, how often?
   ①Frequently ☐
   ②Sometimes ☐
   ③Rarely ☐
7) For what purposes?
   ①Storing things such as grains or clothes ☐
   ②Fishing ☐
   ③Drying meat/ crops ☐
   ④Others (specify)…….

APPENDIX 3 ETHICAL APPROVAL LETTERS

The University of Queensland Institutional Human Research Ethics Approval

REBH Approval Letter: REBH/Approval/2013/014

The Australian National University Ethical Approval

REBH Approval Letter: REBH/Approval/2014/031

THE UNIVERSITY OF QUEENSLAND

Institutional Human Research Ethics Approval

Project Title:	Towards A Spatial Decision Support System (SDSS) For Malaria Elimination In Bhutan
Chief Investigator:	Prof Archie Clements
Supervisor:	None
Co-Investigator(s):	Dr Michelle Gatton, Dr Gerard Kelly, Dr Kinley Wangdi
School(s):	School of Population Health
Approval Number:	2013000884
Granting Agency/Degree:	None
Duration:	31st August 2014

Comments:

Note: If this approval is for amendments to an already approved protocol for which a UQ Clinical Trials Protection/Insurance Form was originally submitted, then the researchers must directly notify the UQ Insurance Office of any changes to that Form and Participant Information Sheets & Consent Forms as a result of the amendments, before action.

Name of responsible Committee:
Medical Research Ethics Committee
This project complies with the provisions contained in the *National Statement on Ethical Conduct in Human Research* and complies with the regulations governing experimentation on humans.

Name of Ethics Committee representative:
Professor Bill Vicenzino
Chairperson
Medical Research Ethics Committee

Signature _____ Date 12 Dec 2013

དཔལ་ལྡན་འབྲུག་གཞུང་།
གསོ་བ་ལྷན་ཁག།

ROYAL GOVERNMENT OF BHUTAN
MINISTRY OF HEALTH
THIMPHU BHUTAN
P.O BOX: 726

REBH/Approval/2013/014 **Date: 22nd August, 2013**

REBH Approval Letter

<table>
<tr><td rowspan="1">PI: Dr Kinley Wangdi
Institute: School of Population Health, The University of Queensland
Country: Brisbane, Queensland</td><td colspan="2">Study Title: Towards a spatial decision support system for malaria elimination in Bhutan</td></tr>
<tr><td rowspan="2">REBH's Decision:
Approved with conditions</td><td>Protocol Version No. 5
Dated: 21st August, 2013</td><td>Informed Consent Version No. 4
Dated: 15th August, 2013</td></tr>
<tr><td colspan="2">Mode of Review: ✓ Full Board Review
Meeting No. 2/2013 (15th)
✓ Expedited Review (for revised versions)</td></tr>
<tr><td colspan="3"><u>Conditions for Approval</u>
1. Final report of the study both in soft and hard copy must be submitted to REBH at the end of the study before publishing.
2. Any changes to the proposal or to the attachments (informed consent and research tools such as forms) should be approved by REBH before implementation
3. The approval for this proposal is valid ONLY for ONE year from the approval date.</td></tr>
</table>

(Dr. Phurb Dorji)
Chairperson-REBH

For further information please contact: *mongal56@health.gov.bt; REBH Member Secretary*

PABX: + 975-2-322602, 322351, 328091, 328092, 328093 Minister: 323973 Fax: 323113 Secretary 326627
Fax: 324649 HRD: Tel/Fax- 323953 Extension 142

Australian National University

25th[h] November 2014

Dear Dr Kinley Wangdi,

Protocol: 2014/633
Evaluation of spatial decision support system in malaria control activities in Bhutan through key informant interview

I am pleased to advise you that your Human Ethics application received approval by the Chair of the Science and Medical DERC on 11 November 2014.

For your information:

1. Under the NHMRC/AVCC National Statement on Ethical Conduct in Human Research we are required to follow up research that we have approved.
Once a year (or sooner for short projects) we shall request a brief report on any ethical issues which may have arisen during your research or whether it proceeded according to the plan outlined in the above protocol.

2. Please notify the committee of any changes to your protocol in the course of your research, and when you complete or cease working on the project.

3. Please notify the Committee immediately if any unforeseen events occur that might affect continued ethical acceptability of the research work.

4. Please advise the HREC if you receive any complaints about the research work.

5. The validity of the current approval is five years' maximum from the date shown approved. For longer projects you are required to seek renewed approval from the Committee.

All the best with your research,

Kim

Ms Kim Tiffen
Human Ethics Manager
Research Integrity & Compliance,
Research Services,
Ground Floor, Chancelry 10B
Ellery Cres,
The Australian National University
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REBH/Approval/2014/031 **15th January,2015**

REBH Approval Letter

PI: Dr. Kinley Wangdi **Institute:** National Center for Epidemiology and Population Health (NCEPH) Research School of Population Health College of Medicine, Biology and Environment The Australian National University	**Study Title**:Evaluation of spatial decision support system in malaria control activities in Bhutan through keyinformant interview
Co-PI: None	
Mode of Review: ✓*Full Board Review (Meeting No. 4/2014)* ☐*Expedited Review*	
Decision: Approved with conditions	
List of document(s) approved: Protocol — Version No.01 Dated: November 25, 2014 Informed Consent Form — Version No.01 Dated: November 25, 2014 Tools (Questionnaire/forms) — Version No.01 Dated: November 25, 2014	

Conditions for Approval

1. *This approval is granted for the scientific and ethical soundness of the study. The PI shall be responsible to seek all other clearances/approvals required by law/policy including NSB Clearances, permission from the study sites, and administrative approval before conducting the study.*
2. *Any changes to the proposal or to the attachments (informed consent and research tools such as forms) should be approved by REBH before implementation*
3. *Report serious adverse events to REBH within 10 working days after the incident and unexpected events should be included in the continuing review report or the final report.*
4. *Final report of the study both in soft and hard copy must be submitted to REBH at theend of the study before publishing.*
5. *This approval is valid till 14th January, 2016. The PI has to apply for the continuing review two months before this validity expires, if the study continues beyond the approved period.*

(Dr. Pakila Drukpa)
Chairperson-REBH

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PABX: + 975-2-322602, 322351, 328091, 328092, 328093 (Extension 333)Fax: 324640

APPENDIX 4 COPIES OF INFORMATION AND CONSENT FORMS

English Consent Form I

Dzongkha Consent Form I

English Information Form II

Dzongkha Information Form II

English Consent Form III

Dzongkha Consent Form III

English Information Form IV

English Informed Consent Form V

Dzongkha Informed Consent Form V

English Consent Form I

Consent Form (Participant's copy)

Full Project Title: Towards a spatial decision support system for malaria elimination in Bhutan
Lay Project Title: Use of geography information system in malaria elimination in Bhutan.

Principal Researchers:

Dr Kinley Wangdi, PhD student, School of Population Health, The University of Queensland

Prof Archie Clements, Professor of Infectious Disease Epidemiology, School of Population Health, The University of Queensland

Dr Michelle Gatton, Queensland University of Technology School of Public Health
Mr Gerard Kelly, School of Population Health, The University of Queensland

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I have:

- read, or have had read to me, and I understand the Participant Information;
- freely agreed to participate in this project according to the conditions in the Participant Information;
- had any questions or queries answered to my satisfaction;
- understood that the project is for the purpose of research and not for treatment;
- understood that I will be informed of my malaria test result and, if it is positive, advised to seek medical attention at the nearest health center, and that the researchers cannot provide malaria treatment; and
- understood that the confidentiality of information relating to me will be maintained and safeguarded.

I will be given a copy of the Participant Information and Consent Form to keep.

The researcher has agreed not to reveal my identity and personal details if information about this project is published or presented in any public form.

Participant's Name (printed) ……..

Signature or ink thumb print Date

Address……..……
……
……

Phone (Hm): …….. (Mb): ….…… (Wk): …….

Name of Witness to Participant's Signature (printed)…….

Signature Date

Note: All parties signing the Consent Form must date their own signature.

Consent Form (Researcher's copy)

Full Project Title: Towards a spatial decision support system for malaria elimination in Bhutan
Lay Project Title: Use of geography information system in malaria elimination in Bhutan.

Principal Researchers:

Dr Kinley Wangdi, PhD student, School of Population Health, The University of Queensland

Prof Archie Clements, Professor of Infectious Disease Epidemiology, School of Population Health, The University of Queensland

Dr Michelle Gatton, Queensland University of Technology School of Public Health
Mr Gerard Kelly, School of Population Health, The University of Queensland

I have:

- read, or have had read to me, and I understand the Participant Information;
- freely agreed to participate in this project according to the conditions in the Participant Information;
- had any questions or queries answered to my satisfaction;
- understood that the project is for the purpose of research and not for treatment;
- understood that I will be informed of my malaria test result and, if it is positive, advised to seek medical attention at the nearest health center, and that the researchers cannot provide malaria treatment; and
- understood that the confidentiality of information relating to me will be maintained and safeguarded.

I will be given a copy of the Participant Information and Consent Form to keep.

The researcher has agreed not to reveal my identity and personal details if information about this project is published or presented in any public form.

Participant's Name (printed) ……..

Signature or ink thumb print Date

Address…….
…….
…….

Phone (Hm): …….. (Mb): ……..…… (Wk): ……

Name of Witness to Participant's Signature (printed)…….

Signature Date

Note: All parties signing the Consent Form must date their own signature.

REVOCATION OF Consent Form (Participant's copy)

Full Project Title: Towards a spatial decision support system for malaria elimination in Bhutan
Lay Project Title: Use of geography information system in malaria elimination in Bhutan.
Principal Researchers:

Dr Kinley Wangdi, PhD student, School of Population Health, The University of Queensland

Prof Archie Clements, Professor of Infectious Disease Epidemiology, School of Population Health, The University of Queensland

Dr Michelle Gatton, Queensland University of Technology School of Public Health
Mr Gerard Kelly, School of Population Health, The University of Queensland

I hereby wish to WITHDRAW my consent to participate in the research proposal described above.

Name .....

Signature .....

Date ...../...../.....

Address .....

.....

.....

REVOCATION OF Consent Form (Researcher's copy)

Full Project Title: Towards a spatial decision support system for malaria elimination in Bhutan
Lay Project Title: Use of geography information system in malaria elimination in Bhutan.
Principal Researchers:

Dr Kinley Wangdi, PhD student, School of Population Health, The University of Queensland

Prof Archie Clements, Professor of Infectious Disease Epidemiology, School of Population Health, The University of Queensland

Dr Michelle Gatton, Queensland University of Technology School of Public Health
Mr Gerard Kelly, School of Population Health, The University of Queensland

I hereby wish to WITHDRAW my consent to participate in the research proposal described above.

Name .....

Signature .....

Date ...../...../.....

Address .....

.....

.....

"I do not wish to take part" - Refusal of Consent Form (Participant's copy)

Full Project Title: Towards a spatial decision support system for malaria elimination in Bhutan
Lay Project Title: Use of geography information system in malaria elimination in Bhutan.

Principal Researchers:

Dr Kinley Wangdi, PhD student, School of Population Health, The University of Queensland

Prof Archie Clements, Professor of Infectious Disease Epidemiology, School of Population Health, The University of Queensland

Dr Michelle Gatton, Queensland University of Technology School of Public Health
Mr Gerard Kelly, School of Population Health, The University of Queensland

By returning this form you are showing that you do not wish to take part in this study.

Participant's Name (printed) ……...

Signature

Date

"I do not wish to take part" - Refusal of Consent Form (Researcher's copy)

Full Project Title: Towards a spatial decision support system for malaria elimination in Bhutan
Lay Project Title: Use of geography information system in malaria elimination in Bhutan.

Principal Researchers:

Dr Kinley Wangdi, PhD student, School of Population Health, The University of Queensland

Prof Archie Clements, Professor of Infectious Disease Epidemiology, School of Population Health, The University of Queensland

Dr Michelle Gatton, Queensland University of Technology School of Public Health
Mr Gerard Kelly, School of Population Health, The University of Queensland

By returning this form you are showing that you do not wish to take part in this study.

Participant's Name (printed) .....

Signature Date

Dzongkha Consent Form I ཁས་ལན་འ་ཨོག། (བཅའ་མར་གཏོགས་མིའི་འཚ་)

ལས་འགུལ་ཡོངས་རྫོགས་ཀྱ་མིང་: འཚུག་ལུ་ཚད་ནད་མ་ལ་རི་ཡ་རྩ་བསླབ་འབབ་ནེའི་དོན་ལུ་ འཕེལ་ཡོད་མཐའ་བཅད་རྒྱབ་སྐྱོར་ལམ་ལུགས་མཐའ་དོན་ལུ། འཚུག་ལུ་ཚད་ནད་མ་ལ་རི་ཡ་རྩ་བསླབ་འབབ་ནེའི་ ས་རིག་བརྟ་དོན་ལས་ལུགས་བསྟར་སྤྱོད།

ཞིབ་འཚོལ་བ་གཙོ་ཅན་:

ཀུན་ལེགས་དཔང་འདུས་ PhD སློབ་ཐུག། མི་རྟོགས་འཛོད་བསྟེན་སློབ་གྲྭ་ཀུ་ཤེནས་ལནྡེ་གཙུག་ལག་སློབ་སྟེ།
ཨེ་སོག། ལེགས་སྩུར་བ་ ཨར་ཅེ་ ཀེ་ལི་མེནྡེགེས། ནང་འབྲལ་ནང་འ ལ་ཡོད་ལེགས་སྩུར་བ། མི་རྟོགས་འཛོད་བསྟེན་སློབ་གྲྭ་ ཀུ་ཤེནས་ལེནྡེ་གཙུག་ལག་སློབ་སྟེ།
མའི་ཀ་ལེ་ གཱ་ཏོན།
ཇི་རའི་ཀེ་ལེ། མི་རྟོགས་འཛོད་བསྟེན་སློབ་གྲྭ་ ཀུ་ཤེནས་ལེནྡེ་གཙུག་ལག་སློབ་སྟེ།

ང་གིས་:

- འདི་ཡྱག་ཞིན་ལས་ ཡང་ན་ གཞན་གིས་ དེའི་དོན་ལུ་ཡྱག་ཞིན་ལས་ ང་གིས་བཅའ་མར་གཏོགས་མའི་བརྟ་དོན་ཚུ་ལེགས་ཏོས་སྟེ་ཤ་གོ་ཡི།
- བཅའ་མར་གཏོགས་མའི་བརྟ་དོན་དང་འབྲེལ་ཏེ་ ལས་འགུལ་འདི་ནང་ རང་མོས་ཐོག་ལས་ བཅའ་མར་གཏོགས་ནེ་ཞིན།
- ི་བ་ཡོད་མི་ཚུ་ ང་རང་གི་སྤྲོ་ཚོམ་དང་ཕྱན་ཐོག་ལས་ ལན་ཐོབ་ཅི།
- ལས་འགུལ་འདི་ སྐན་བཅོས་ཀྱི་དོན་ལུ་མེན་པར་ ཞིབ་འཚོལ་ཀྱི་དོན་ལུ་ཞིནམ་ཤ་ཤ་གོ་ཡི།
- བརྟ་དོན་ཚུ་གསང་བའི་ཐོག་ལུ་ ཉེན་སྐྱང་དང་ཕྱན་སྤེ་བཞག་ནི་ཞིནམ་ཤ་གོ་ཡི།
- གནང་བའི་ཐོག་ལས་ གསོ་བའི་ལག་ལེན་པ་དང་ གཞན་འཛོད་བསྟེན་ལྷུད་རིག་གི་ལུ་འབད་མི་ དེ་ལས་ སྐན་ཁང་ནང་སྐན་བཅོས་འབད་མི་ཚུ་ལུ་ འཕེལ་ཡོད་ནང་གཞི་སྐོར་ སྐན་བཅོས་འབད་ནེའི་དགོས་དོན་དང་འཕྲལ་ཤ་ཤ་ཞིན་ ཞིབ་འཚོལ་པ་ཚུ་ དེ་ལས་ གཞུང་ཁང་ནང་སྐན་བཅོས་འབད་མི་ཚུ་ལུ་ ཞིབ་འཚོལ་ཀྱི་ཁ་ཐུག་ཡོད་ཅི།

ང་ལུ་ རང་དང་གཅིག་ཁར་བཞག་ནེའི་དོན་ལུ་ བཅའ་མར་གཏོགས་ནེའི་བརྟ་དོན་དང་ཁས་ལན་འབྱེད་ཨོག་འཛོག།

ཞིབ་འཚོལ་པ་གིས་ ལས་འགུལ་གི་བརྟ་དོན་ཚུ་ དེའི་བསྐྱན་དང་གསལ་སྟོན་འབད་དགོ་པ་ཅིན་ དེའི་ངོ་སྤྲོད་དང་ང་རང་གི་ཁ་གསལ་ཚུ་ གསལ་སྟོན་མི་འབད་ནེའི་ཁ་འཚམ་ཅི།

བཅའ་མར་གཏོགས་མིའི་ངོ་མིང་ (པར་བསྐྱན་)

.....

མིང་རྟགས་ ཚེས་

ཁ་བྱང་.....

.....

.....

..... བཏུང་འཕྲིན་ཨང་ (Hm): ..... (Mb):

..... (Wk): .....

བཅའ་མར་གཏོགས་མིའི་དཔང་ཡིའི་མིང་དང་མིང་རྟགས་(པར་བསྐྱན)....

• མིང་རྟགས་ ཚེས་

ཁས་ལན་འོ་ཨོག (ཞིབ་འཚོལ་བའི་འདུ)

ལས་འགུལ་ཡོངས་རྫོགས་ཀྱ་མིང་: འབྲུག་ལུ་ཚང་ནད་མ་ལ་རི་ཡ་རྩ་བསྒྲུབ་འབད་ནི་དོན་ལུ་ འཕེལ་ཡོད་མཐའ་བཅད་རྒྱབ་སྐྱོར་ལམ་ལུགས་མཐའ་དོན་ལུ། འབྲུག་ལུ་ཚང་ནད་མ་ལ་རི་ཡ་རྩ་བསྒྲུབ་འབད་ནི། ས་རིག་བརྡ་དོན་ལམ་ལུགས་བསྟར་སྦྱོང་།

ཞིབ་འཚོལ་བ་གཙོ་ཅན་:

ཀུན་ལེགས་དཔང་འདུས་ PhD སློབ་ཁྲིགཔ། མི་རྟོགས་འཛོད་བསྟེན་སློབ་གྲྭ་ཀུ་ཤེནཞི་ལནའི་གཙུག་ལག་སློབ་སྟེ།
ཚེ་སོག་ ལེགས་སྩར་བ་ ཚར་ཅི་ ཀི་ལི་ནེནའིས། ནད་འབྲུབ་ནང་འ་ལ་ཡོད་ལེགས་སྩར་བ། མི་རྟོགས་འཛོད་བསྟེན་སློབ་གྲྭ་ ཀུ་ཤེནཞི་ལནའི་གཙུག་ལག་སློབ་སྟེ།
མའི་ཀ་ལེ་ ག་ཏོན།
ཇི་རྟའི་ཀེ་ལེ། མི་རྟོགས་འཛོད་བསྟེན་སློབ་གྲྭ་ ཀུ་ཤེནཞི་ལནའི་གཙུག་ལག་སློབ་སྟེ།

ང་ཚོས་:

- འདི་ཕྱག་ཞེན་ལས་ ཡང་ན་ གཞན་ཚོས་ དེའི་དོན་ལུ་ཕྱག་ཞེནམ་ལས་ ང་ཚོས་བཙའ་མར་གཏོགས་མའི་བརྡ་དོན་ཚུ་ལེགས་ཐོམ་སྟེ་ཏ་གོ་ཡི།
- བཙའ་མར་གཏོགས་མའི་བརྡ་དོན་དང་འབྲེལ་ཏེ་ ལས་འགུལ་འདི་ནང་ རང་མོས་ཐོག་ལས་ བཙའ་མར་གཏོགས་ནི་ཞིན།
- ི་ག་ཡོད་མི་ཚུ་ ང་རང་གི་བློ་ཆོམ་དང་ཕྲན་ཐོག་ལས་ ལན་ཐོབ་ཅི།
- ལས་འགུལ་འདི་ སྐན་བཙོས་ཀྱི་དོན་ལུ་མེན་པར་ ཞིབ་འཚོལ་གྱི་དོན་ལུ་ཞིནམ་ཏ་གོ་ཡི།
- བརྡ་དོན་ཚུ་གསང་བའི་ཐོག་ལུ་ ཉེན་སྐྱང་དང་ཕྲན་སྟེན་བཞག་ནི་ཞིནམ་ཏ་གོ་ཡི།
- གནང་བའི་ཐོག་ལས་ གསོ་བའི་ལག་ལེན་པ་དང་ གཞན་འཛོད་བསྟེན་ཁྲད་རིགཔ་ལུ་ དེ་ལས་ སྐན་ཁང་ནང་སྐན་བཙོས་འབད་མི་ཚུ་ལུ་ འཕེལ་ཡོད་ནད་གཞི་སྐོར་ སྐན་བཙོས་འབད་ནིའི་དགོས་དོན་དང་འཁྱིལ་ཏེ་ ཞིབ་འཚོལ་འབད་ནི་དང་ གསང་བའི་ཐོག་ལུ་བཞག་ནི་ཞིནམ་ཏ་གོ་ཡི།

ང་ལུ་ རང་དང་གཅིག་ཁར་བཞག་ནིའི་དོན་ལུ་ བཙའ་མར་གཏོགས་ནིའི་བརྡ་དོན་དང་ལས་ལན་འཕྲི་ཐོག་འཛོད།

ཞིབ་འཚོལ་བ་གིས་ ལས་འགུལ་གི་བརྡ་དོན་ཚུ་ དབེ་བསྒྲུན་དང་གསལ་སྟོན་འབད་དགོ་པ་ཅིན་ དེའི་ངོ་སྤྲོད་དང་ང་རང་གི་ཁ་གསལ་ཚུ་ གསལ་སྟོན་མི་འབད་ནིའི་ཁ་འཚམ་ཅི།

བཙའ་མར་གཏོགས་མིའི་ངོ་མིང་ (པར་བསྒྲུན་)

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མིང་རྟགས་ ཚེས་

ཁ་བྱང་.....

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..... བསྒྲུད་འཛིན་ཚད་ (Hm): ..... (Mb):

..... (Wk): .....

བཙའ་མར་གཏོགས་མིའི་དཔང་ཡིའི་མིང་དང་མིང་རྟགས་(པར་བསྒྲུན).....

• མིང་རྟགས་ ཚེས་

ཁས་ལན་དགོངས་ཞུའི་འཕྲི་ཐོག་ (བཅའ་མར་གཏོགས་མིའི་འདུ)

ལས་འགུལ་ཡོངས་རྫོགས་ཀྱི་མིང་: འབྲུག་ལུ་ཚད་ནད་མ་ལ་རེ་ཡ་རུ་བསྒང་འབད་ནི་དོན་ལུ་ འཛེལ་ཡོད་མཐའ་བཅད་རྒྱབ་སྐྱོར་ལམ་ལུགས་མཐའ་དོན་ལུ། འབྲུག་ལུ་ཚད་ནད་མ་ལ་རེ་ཡ་རུ་བསྒང་འབད་ནི། ས་རིག་བརྡ་དོན་ལམ་ལུགས་བསྟར་སྦྱོང་།

ཞིབ་འཚོལ་བ་གཙོ་ཅན:

ཀུན་ལེགས་དབང་འདུས་ PhD སློབ་སྡུག། མི་རློབས་འཛོད་བསྟེན་སློབ་གྲྭ་ ཀུ་ཤེནས་ལནའི་གསུག་ལག་སློབ་སྡེ།
ཚེ་སོག་ ལེགས་སྦྱར་བ་ ཨར་ཅི་ ཀེ་ལི་མེནའིས། ནད་འབྱུབ་ནང་འ་ལ་ཡོད་ལེགས་སྦྱར་བ། མི་རློབས་འཛོད་བསྟེན་སློབ་གྲྭ་ ཀུ་ཤེནས་ལེནའི་གསུག་ལག་སློབ་སྡེ།
མའི་ཀ་ལེ་ གཱ་ཏོན།
ཇི་ཏའི་ཀེ་ལེ། མི་རློབས་འཛོད་བསྟེན་སློབ་གྲྭ་ ཀུ་ཤེནས་ལེནའི་གསུག་ལག་སློབ་སྡེ།

ང་ཚང་གིས་ དང་འདོད་དང་འབྲེལ་ཏེ་ གོང་གསལ་ཞིབ་འཚོལ་ཐོས་འཆར་གྱི་ཁས་ལན་ལས་དགོངས་ཞུ་ནི་ཨིནམ་ལས་ དགོངས་ཞུ་འདི་གིས་ ང་ཚང་གི་སྐན་བཙོས་དང་ སྐན་བཙོས་འབད་མི་ཚུའི་འཛེལ་བ་ལུ་མི་གནོད་པའི་ངོས་ལེན་ལུ་

མིང་.....

.....མིང་རྟགས་

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..... ཚེས་ ...../...../.....

ཁ་བྱང་

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ཁས་ལན་དགོངས་ཞུའི་འབྲི་རྟོག་ (ཞིབ་འཚོལ་པའི་འདུ་)

ལས་འགྱལ་ཡོངས་རྫོགས་ཀྱ་མིང་: འབྲུག་ལུ་ཚད་ནད་མ་ལ་རི་ཡ་རྩ་བསྐྱང་འབད་ནི་དོན་ལུ་ འབྲེལ་ཡོད་མཐའ་བཅད་རྒྱབ་རྟེན་སྐྱོར་ལམ་ལུགས་མཐའ་དོན་ལུ། འབྲུག་ལུ་ཚད་ནད་མ་ལ་རི་ཡ་རྩ་བསྐྱང་འབད་ནིའི་ ས་རིག་བརྡ་དོན་ལམ་ལུགས་བསྟར་སྦྱོང་།

ཞིབ་འཚོལ་བ་གཙོ་ཅན་:

ཀུན་ལེགས་དབང་འདུས་ PhD སློབ་ཁྲག། མི་རྟོགས་འཛོད་བསྟེན་སློབ་གྲྭ་ ཀུ་ཤེནི་ལནྡེ་གཙུག་ལག་སློབ་ཁྲ།
ཇེ་སོཁ་ ལེགས་སྦྱར་བ་ ཨར་ཚི་ ཀེ་པི་མེནྡེའི། ནད་འབྲུབ་ནང་འ་ལ་ཡོད་ལེགས་སྦྱར་བ། མི་རྟོགས་འཛོད་བསྟེན་སློབ་གྲྭ་ ཀུ་ཤེནི་ལེནྡེ་གཙུག་ལག་སློབ་ཁྲ།
མའི་ཀ་ལེ་ གཱ་ཏྲོན།
ཇི་རཀྵི་ཀེ་ལེ། མི་རྟོགས་འཛོད་བསྟེན་སློབ་གྲྭ་ ཀུ་ཤེནི་ལེནྡེ་གཙུག་ལག་སློབ་ཁྲ།

ང་རང་གིས་ དང་འདོད་དང་འཁྲིལ་ཏེ་ གོང་གསལ་ཞིབ་འཚོལ་གོས་འཆར་གྲི་ཁས་ལན་ལས་དགོངས་ཞུ་ནི་ཨིནམ་ལས་ དགོངས་ཞུ་འདི་གིས་ ང་རང་གི་སྐན་བཙོས་དང་ སྐན་བཙོས་འབད་མི་ཚུའི་འཛེལ་བ་ལུ་མི་གཏོང་བའི་ངོས་ལེན་ལུ་

མིང་.....

.....མིང་རྟགས་

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..... ཚེས་ ...../...../.....

ཁ་བྱང་

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“ང་བཅའ་མར་གཏོགས་འདོད་མེད་” – ལས་ལན་འཁྱི་ཐོག་ངོས་མེད། (བཅའ་མར་གཏོགས་མིའི་འདུ)

ལས་འགུལ་ཡོངས་རྫོགས་ཀྱི་མིང་: འབྲུག་ལུ་ཚད་ནད་མ་ལ་རེ་ཡ་རྩ་བསྐྱད་འབད་ནི་དོན་ལུ་ འཕེལ་ཡོད་མཐའ་བཅད་རྒྱབ་སྐྱོར་ལམ་ལུགས་མཐའ་དོན་ལུ། འབྲུག་ལུ་ཚད་ནད་མ་ལ་རེ་ཡ་རྩ་བསྐྱད་འབད་ནི། ས་རིག་བརྟ་དོན་ལམ་ལུགས་བསྟར་སྦྱོང་།

ཞིབ་འཚོལ་བ་གཙོ་ཅན:

ཀུན་ལེགས་དབང་འདུས་ PhD སློབ་ཁྲག། མི་རློབས་འཛོད་བསྟེན་སློབ་གྲྭ་ ཀུ་ཤེནས་ལནའི་གཙུག་ལག་སློབ་ཕྲེ།
ཚེ་སོག་ ལེགས་སྩར་བ་ ཨར་ཅི་ ཀེ་ལི་མེནཏིས། ནད་འབྱབ་ནང་འ་ལ་ཡོད་ལེགས་སྩར་བ། མི་རློབས་འཛོད་བསྟེན་སློབ་གྲྭ་ ཀུ་ཤེནས་ལེནའི་གཙུག་ལག་སློབ་ཕྲེ།
མའི་ཀ་ལེ་ གཱ་ཏོན།
ཇི་རའི་ཀེ་ལེ། མི་རློབས་འཛོད་བསྟེན་སློབ་གྲྭ་ ཀུ་ཤེནས་ལེནའི་གཙུག་ལག་སློབ་ཕྲེ།

འབྲི་ཧོག་ལོག་སྒྲུབ་མི་དེ་ ཞིབ་འཇུག་ནང་དང་འདོད་མེད་པའི་ངོས་འཛིན་འབད་ཡ་ཨིན།

བཅའ་མར་གཏོགས་མིའི་ངོ་མིང་ (པར་བསྐྲན་)

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མིང་རྟགས་དང་ཚེས་

“ང་བཅའ་མར་གཏོགས་འདོད་མེད་” ཞེས་ལན་འཕྲི་རོགས་ངོས་མེད། (ཞིབ་འཚོལ་པའི་འདུ)

ལས་འགུལ་ཡོངས་རྫོགས་ཀྱི་མིང་ འདུག་ལུ་ཚད་ནད་མ་ལ་རི་ཡ་རྩ་བསྐྱང་འགང་ནི་དན་ལུ་ འདེལ་ཡོད་མཐའ་བཅད་རྒྱབ་སྐྱོར་ལམ་ལུགས་མཐའ་དོན་ལུ། འདུག་ལུ་ཚད་ནད་མ་ལ་རི་ཡ་རྩ་བསྐྱང་འབད་ནིའི་ ས་རིག་བརྡ་དོན་ལམ་ལུགས་བསྟར་སྤྱོད།

ཞིབ་འཚོལ་བ་གཙོ་ཅན་:

ཀུན་ལེགས་དབང་འདུས་ PhD སློབ་ཁྲིག། མི་རློབས་འཛོད་བསྟེན་སློབ་ཐུ་ རིག་ཤེནས་ལནདྲེ་གནུག་ལག་སློབ་སྟེ།
ཚེ་སོག་ ལེགས་སྩར་བ་ ཚར་ཅི་ ཀི་ལི་མེནདྲེས། ནད་འབྱབ་ནང་འ ་ལ་ཡོད་ལེགས་སྩར་བ། མི་རློབས་འཛོད་བསྟེན་སློབ་ཐུ་ རིག་ཤེནས་ལེནདྲེ་གནུག་ལག་སློབ་སྟེ།
མའི་ཀ་ལེ་ གཱ་ཏོན།
ཇི་རའྲི་ཀེ་ལེ། མི་རློབས་འཛོད་བསྟེན་སློབ་ཐུ་ རིག་ཤེནས་ལེནདྲེ་གནུག་ལག་སློབ་སྟེ།

འབྲི་ཤོག་ལོག་སྟོང་མི་དེ་ ཞིབ་འཚུག་ནང་དང་འདོད་མེད་པའི་ངོས་འཛིན་འབད་ཁ་ཤེན།

བཅའ་མར་གཏོགས་མིའི་ངོ་མིང་ (པར་བསྐྲུན་)

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མིང་རྟགས་དང་ཚེས་

English Consent Form II

PARTICIPANT INFORMATION and CONSENT FORM

Full Project Title: Towards a spatial decision support system for malaria elimination in Bhutan
Lay Project Title: Use of geography information system in malaria elimination in Bhutan.
Principal Researchers:

Dr Kinley Wangdi, PhD student, School of Population Health, The University of Queensland
Prof Archie Clements, Professor of Infectious Disease Epidemiology, School of Population Health, The University of Queensland

Dr Michelle Gatton, Queensland University of Technology School of Public Health
Mr Gerard Kelly, School of Population Health, The University of Queensland

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1. Your Consent

You are invited to take part in a research project. This Participant Information document contains detailed information about this research project. Its purpose is to explain to you as openly and clearly as possible all the procedures involved in this project before you decide whether or not to take part in it.

2. Purpose and Background

The purpose of this project is to determine whether the population living in the malaria endemic districts of Bhutan carry malaria infection in their blood without presenting with symptoms such as fever, headache and generalized body ache. We will investigate this through examination of blood using a rapid diagnostic test. This will involve in collection of two drops (5 µl) of blood.

3. Procedures

All eligible people who have been living if the locality for more than eight weeks will be enrolled for the research through submission of blood sample for testing. The blood collection will be carried out by a malaria technician. Agreeing to take part in the study means that you are willing to do the following:
1) Have the blood examined for malaria parasites in your blood sample

4. Possible Benefits

There might not be any direct benefits to you; the research will result in a better understanding of the parasite in blood of the people living in the malaria controlled areas.

The finding of the study/research will aid in the effective preventive and control of the malaria.

5. Possible Risks

We anticipate that there are no risks of injury or illness involved in participating in this research. If your test result is positive for malaria, you will be notified immediately (the test is done in your presence) and advised to seek medical assistance in the nearest health center. The researchers cannot provide malaria treatment. The method of diagnosis is a rapid diagnostic test that is widely used to identify people with malaria infections. It is used by the Bhutan Ministry of Health and has been shown to be highly accurate. However, we cannot guarantee that the accuracy is perfect and a small number of infections (<10%) could be missed; additionally a small number of people (<10%) who are indicated by the test to have a malaria infection might not actually have the infection. Therefore, it is important that if you experience symptoms of malaria such as fever, headache and generalized body ache should seek medical advice in the nearest health center.

6. Alternatives to Participation

If individuals choose not to participate they can seek information on risk of malaria from the nearest health center.

7. Privacy, Confidentiality and Disclosure of Information

Any information which will be obtained during the blood examination will not be disclosed to anyone other than the study researchers and will remain confidential and anonymous. Also, your results from the study will only be revealed to the researchers. We intend to give you feedback on the results of the project when available. When the results of the study are published or presented, we will ensure that you will remain anonymous.

8. New Information Arising During the Project

During the research project, new information about the risks and benefits of the project may become known to the researchers. If this occurs, you will be informed right away.

9. Results of Project

When you join this research project you will be invited to let the researchers know if you are interested in hearing about the final results of the research. The result will be made known to you immediately following the blood test.

10. Further Information or Any Problems

If you need more information or if you have any problems about this project, you can contact any of the researchers. The researcher responsible for this project is:

- Kinley Wangdi, dockinley@gmail.com

11. Participation is Voluntary

Taking part in any research project is voluntary. If you do not wish to take part you are not obliged to. If you decide to take part and later change your mind, you are free to withdraw from the project at any stage.

Before you make your decision, a member of the research team will be available to answer any questions you have about the research project. You can ask for any information you want. You may also wish to discuss the project with a health worker. Sign the Consent Form only after you have had a chance to ask your questions and have received satisfactory answers. If you decide to withdraw from this project, please notify a member of the research team before you withdraw.

12. Ethical Guidelines and other issues

This project will be carried out according to the norms set by Research Ethics Board of Health (REBH) Ministry of Health, Bhutan and the ethical board of University of Queensland. This statement has been developed to protect the interests of people who agree to participate in human research studies.

13. Reimbursement for your costs

You will not be paid for taking part in this project. We do not anticipate any out of pocket expenses to you as a part of your participation.

14. Final instructions

Following contact with the study researchers, if you are interested in participating, you will be asked to sign and hand to the researcher the 'Consent Form (Researcher's copy)'.

This study adheres to the Guidelines of the ethical review process of The University of Queensland and the *National Statement on Ethical Conduct in Human Research*. Whilst you are free to discuss your participation in this study with project staff (contactable on +61 (0) 7 3346 4706), if you would like to speak to an officer of the University not involved in the study, you may contact the Ethics Coordinator on +61 (0) 7 3365 3924.

Dzongkha Consent Form II

བཅའ་མར་གཏོགས་མིའི་བརྡ་དོན་དང་ཁས་ལེན།

ལས་འགུལ་ཡོངས་རྫོགས་ཀྱི་མིང་: འབྲུག་ལུ་ཚད་ནད་མ་ལ་རིལ་ཡ་རུ་བསྒྲུབ་འབད་ནིའི་དོན་ལུ་ འབེལ་ཡོད་མཐའ་བཅད་ཆུབ་སྐྱོར་ལམ་ལུགས་མཐའ་དོན་ལུ།
ལས་འགུལ་བགོ་བཀྲམ་མིང: འབྲུག་ལུ་ཚད་ནད་མ་ལ་རིལ་ཡ་རུ་བསྒྲུབ་འབད་ནིའི་ ས་རིག་བརྡ་དོན་ལམ་ལུགས་བསྟར་སྤྱོད།
ཀུན་ལེགས་དཔང་འདུས་ PhD སློབ་ཕྲུག། མི་རྟོགས་འཛོད་བསྟེན་སློབ་གྲྭ་ ཀུ་ཕྱེས་ལེནཏི་གཙུག་ལག་སློབ་སྟེ།
ཞེ་སོག་ ལེགས་སྦྱངས་བ་ ཞར་ཅི་ ཀི་ལི་མེནཏིས། ནད་འབྲུབ་ནང་འཛེལ་ཡོད་ལེགས་སྦྱངས་བ། མི་རྟོགས་འཛོད་བསྟེན་སློབ་གྲྭ་ ཀུ་ཕྱེས་ལེནཏི་གཙུག་ལག་སློབ་སྟེ།
མའི་ཀ་ལེ་ ཀ་ཏོན།
ཇི་རའི་ཀེ་ལེ། མི་རྟོགས་འཛོད་བསྟེན་སློབ་གྲྭ་ ཀུ་ཕྱེས་ལེནཏི་གཙུག་ལག་སློབ་སྟེ།

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༡. ཆོད་རའི་ཁས་བླངས།
ཆོད་ར་ ཞིབ་འཚོལ་ལས་འགུལ་ནང་བཅའ་མར་གཏོགས་གནད། བཅའ་མར་གཏོགས་མིའི་བརྡ་དོན་ཡིག་ཆའི་ནང་ ཞིབ་འཚོལ་ལས་འགུལ་གྱི་བརྡ་དོན་སྐོར་གསལ་བཀོད་འབད་དེ་ཡོད། ཆོད་ར་ བཅའ་མར་གཏོགས་ནི་ཞིན་ན་དང་མེན་ནའི་ཐག་མ་གཅོད་པའི་ཉེ་མར་ལས་འགུལ་ནང་ཡོད་པའི་བྱ་རིམ་ཚུ་ གཅེདཔག་བཏགས་ཁ་གསལ་སྟེ་ གསལ་བཤད་འབད་ནིའི་དོན་ལུ་ཞིན།

༢. གནད་དོན་དང་ཆུབ་ཁྱངས།
ལས་འགུལ་འདི་གི་གནད་དོན་གཙོ་བོ་དང་ འབྲུག་ལུ་ ཚད་ནད་མ་ལ་རིལ་ཡ་དང་ཁྱབ་གནས་རེས་ཀྱི་རྩོད་ཁག་ཚུའི་ནང་ སྤོད་མི་ མི་རྟོགས་ཚུ་ དོད་འབར་དང་ མགུ་ན་ དེ་ལས་ སྤྱིར་བཏང་གཟུགས་ན་ནི་ལ་སོགས་པའི་ ན་ལུགས་མེད་པའི་ཐོག་ལས་ ཁག་གི་རྒྱུད་ལམ་ནང་ མ་ལ་རིལ་ཡ་གིས་ གནོད་པའི་ ཉེན་ཁ་ཡོད་ཀྱི་ཞིན་ན་དང་ མེན་པའི་སྐོར་ གཏན་འཁེལ་བཟོ་ནི། ང་བཅས་ཚུ་གིས་ ཁག་བརྒྱ་དཔྱད་འབད་ཐོག་ལས་ ཞིབ་དཔྱད་འབད་ནི་ཞིན།

༣. བྱ་རིམ།
ས་གནས་ནང་ ཟླ་ངོ་ལས་ལྷག་སྟེ་སྤྱོད་མི་ཚུ་གར་ ཞིབ་འཚོལ་ནང་ བཅའ་མར་གཏོགས་ནིའི་ འོས་འབབ་ཡོད་པ་ལས་ ཁག་གི་དཔེ་མཚོན་ཚུ་བྱིན་ཆོག།
ཁག་ཚུ་ མ་ལ་རིཡའི་འཕྲུལ་ལསཔ་ཚུ་གིས་ བསྟུ་ལེན་འབད་ནི་ཞིན།
ཞིབ་འཚོལ་ནང་བཅའ་མར་གཏོགས་ནིའི་ངོས་ལེན་འབད་མི་དེ་ གཤམ་གསལ་ནང་ བཅའ་མར་གཏོགས་ནིའི་ཁས་ལེན་ཡོད་པ་སྟེ་བཏུ་ནི་ཞིན།

༡) ཆོད་ཀྱི་ཁག་དཔེ་ནང་ མ་ལ་རིཡའི་བརྒེན་པའི་ནད་འབྲུབ་ཡོད་མེད་བརྟག་དཔྱད་འབད་དགོ།

༤. ཨན་ཐོགས་ནིའི་འོས་འབབ།
ཆོད་ལུ་ཐད་ཀར་དུ་ ཁེ་ཨན་མེད་པ་བཟུམ་ཅིག་ཞིན་རྟུང་
ཞིབ་འཚོལ་འདི་གིས་ མ་ལ་རི་ཡ་བཀག་ཐབས་འབད་སའི་ས་ཁོངས་ནང་སྤོད་མི་ཚུའི་ཁག་ནང་ བརྒེན་པའི་ནད་འབྲུབ་ཚུའི་ཁ་རྐྱེགས་

ལེགས་ཤེས་སྒེ་འཐོབ་ཚུགས།
ཞིབ་འཚོལ་ནང་ལས་ཐོབ་མི་གནད་དོན་ཚུ་ མ་ལ་རི་ཡ་སྟོན་འགོག་དང་བཀག་ཐབས་ཀྱི་དོན་ལུ་ ལག་ལེན་འཐབ་ནི་ཨིན།

༤. ཉེན་ཁའི་འོས་འབབ།
ཞིབ་འཚོལ་ནང་བཅའ་མར་གཏོགས་ཞིནམ་ལས་ གནོད་སྐྱོན་དང་ན་ནི་ལ་སོགས་པའི་ ཉེན་ཁ་མེད།
གལ་སྲིད་ མ་ལ་རི་ཡའི་ནང་རྒྱགས་ རྩོད་འབར་དང་མཐུན་ དེ་ལས་ སྤྱིར་བཏང་གཟུགས་ན་ནི་ལ་སོགས་པ་འབྱུང་པ་ཅིན་ ཉེ་འདབས་ཀྱི་གསོ་པའི་འཚོད་བསྟེན་ལྷེ་བ་ལས་ བསྒྲབ་སྟོན་ལེན་དགོ།

༥. བཅའ་མར་གཏོགས་མི་ཚུའི་གདམ་ཁ་
གལ་སྲིད་ ངོ་རྒྱངས་སོ་སོ་གིས་ བཅའ་མར་གཏོགས་འདོད་མེད་པ་ཅིན་ ཉེ་འདབས་ཀྱི་གསོ་བའི་འཚོད་བསྟེན་ལྷེ་བ་ལས་ མ་ལ་རི་ཡའི་ཉེན་ཁའི་སྐོར་བཏང་སྙོམས་ཟིན་དགོ།

༦. སྐེར་དང་ གསང་བ་ དེ་ལས་ བརྟོན་གཞན་ལུ་མི་སྟོན།
ཁག་གི་བརྟག་དཔྱད་འབད་བའི་སྐབས་ལུ་ བརྟོན་ཐོག་མི་ཚུ་གིས་ ཞིབ་འཚོལ་བ་ཚུ་རྒྱངས་གཅིག་མ་གཏོགས་ གཞན་ལུ་མ་བཏོན་པར་ གསང་བའི་ཐོག་ལུ་བཞག་ནི་ཨིན།
དེ་གིས་མ་ཚད་ ཁྱོད་རའི་བརྟག་དཔྱད་སྒྲུབ་འབྲས་ཚུ་ ཞིབ་འཚོལ་པ་ཚུ་ལུ་རྒྱངས་གཅིག་བཏོན་ནི་ཨིན།
ལས་འགུལ་གྱི་སྒྲུབ་འབྲས་ཚུ་བཏོན་པའི་ཤུལ་ལས་ ཁྱོད་ལུ་འབྲེལ་བ་འཐབ་ནིའི་རེ་ཤེ་བ་ཡོད།
ཞིབ་འཚྲག་གི་སྒྲུབ་འབྲས་ཚུ་ དེའི་བསྒྲུན་འབད་དེ་ གསལ་སྟོན་འབད་བའི་སྐབས་ ཁྱོད་ཀྱི་སྐོར་ལས་ གསང་བའི་ཐོག་ལུ་གནས་ནི་ཨིན།

༧. ལས་འགུལ་གྱི་སྐབས་ལུ་ བརྟོན་གསར་པ།
ཞིབ་འཚོལ་ལས་འགུལ་གྱི་སྐབས་ ལས་འགུལ་གྱི་ཉེན་ཁ་དང་ཤན་ཐོགས་བརྟོན་གསར་ཚུ་ ཞིབ་འཚོལ་པ་ཚུ་གིས་ཤེས་པ་བཟོ་ནི་ཨིན། གལ་སྲིད་ འདི་བཟུམ་འབྱུང་ཅིན་ དེ་འཕྲལ་ལས་ཁང་ ཁྱོད་ལུ་བརྟོན་འགན་འབད་ནི་ཨིན།

༨. ལས་འགུལ་སྒྲུབ་འབྲས།
ཁྱོད་ར་ ཞིབ་འཚོལ་ལས་འགུལ་འདི་ནང་བཅའ་མར་གཏོགས་ཞིནམ་ལས་ ཞིབ་འཚོལ་བ་ཚུ་གིས་ ཁྱོད་ར་ མཐའ་བཅད་སྒྲུབ་འབྲས་ཀྱི་དབང་དོད་ཡོད་མེད་སྐོར་དྲིས་ཞིནམ་ལས་ ཁྱོད་ལུ་ ཤེས་རྟོགས་བྱིན་འོང།

༡༠. བརྟོན་ཁ་སྐོང་ ཡང་ན་ དཀའ་ངལ་ཡོད་པ་ཅིན།
གལ་སྲིད་ཁྱོད་ར་ ལས་འགུལ་གྱི་སྐོར་ལས་ བརྟོན་ཁ་སྐོང་དགོ་པ་ཅིན་ ཡང་ན་ གལ་སྲིད་ ཁྱོད་ལུ་ དཀའ་ངལ་རེ་ཡོད་པ་ཅིན་ ཞིབ་འཚོལ་བ་གང་རུང་དང་གཅིག་ཁར་འབྲེལ་བ་འཐབ་གནང།
ལས་འགུལ་གྱི་འགན་ཁྲི་འབགཝ་མི་ཞིབ་འཚོལ་བ་
ཀུན་ལེགས་དབང་འདུས་ dockinley@gmail.com

༡༡. ཁས་བླངས་ཀྱི་ཐོག་ལས་ བཅའ་མར་གཏོགས་ནི།
ཁས་བླངས་ཐོག་ལས་ ཞིབ་འཚོལ་ནང་བཅའ་མར་གཏོགས་གནད།
གལ་སྲིད་ཁྱོད་ར་ བཅའ་མར་གཏོགས་འདོད་མེད་པ་ཅིན་ འགལ་བ་མེད། གལ་སྲིད་བཅའ་མར་གཏོགས་པའི་ཤུལ་ལས་ སེམས་འགྱུར་བ་ཅིན་ ནམ་ར་ཡིན་རུང་ དགོངས་ཚུ་ཆོག།
ཁྱོད་ལ་ཐག་མ་བཅད་པའི་ཉེ་མར་ ཞིབ་འཚོལ་ལས་འགུལ་གི་སྐོར་ལས་ དོགས་པའི་དྲི་བ་རེ་ཡོད་པ་ཅིན་ ཞིབ་འཚོལ་འབྲས་མི་ཚུ་གིས་ གསལ་ཐབས་འབད་འོང།
ཁྱོད་རའི་དང་འདོད་དང་འཁྲིལ་ཏེ་ བརྟོན་གཅིག་ཅིག་ཤོས་དང་ ལས་འགུལ་གྱི་སྐོར་ལས་ འཚོད་བསྟེན་ལས་མི་དང་གཅིག་ཁར་ བསྟུན་ཐོས་འབད་ཚུགས།
ཁྱོད་ཀྱིས་ དེ་བ་ཚུ་དྲིས་ཏེ་ ཐུ་དང་ལྡན་ཏོག་ཏོ་ཐོག་ལས་ ལན་ཚུ་ཐོབ་ཞིནམ་ལས་རྒྱངས་གཅིག་ འགན་ལན་འབྱི་ཤོག་གུ་མིང་རྟགས་བཀོད་དགོ།

གལ་སྲིད་ ལས་འགྱུལ་ལས་ དགོངས་མ་ཞུ་དགོ་པ་ཅིན་ དགོངས་མ་མ་ཞུ་བའི་ཉེ་མར་ ཞིབ་འཚོལ་སྤེ་ཚན་གྱི་འཐུས་མི་གང་རུང་དང་གཅིག་ འབྲེལ་བ་འཐབ་གནད།

༡༤. ལས་སྟོན་རྣམ་གཞག་དང་གནད་དོན་གཞན།
ལས་འགྱུལ་འདི་ འབྲུག་ གསོ་བའི་ལྷན་ཐག་ འཕྲོད་བསྟེན་ཞིབ་འཚོལ་རྣམ་གཞག་ཆོགས་ཆུང་གི་སྒྲིག་ཁྲིམས་དང་ ཀུ་ཕྱེགས་ལེན་ཞི་གཙུག་ལག་སློབ་སྟེའི་རྣམ་གཞག་ཆོགས་ཆུང་དང་འཁྲིལ་ཏེ་ འབད་ནི་ཡིན།
གནད་དོན་འདི་ འགྲོ་བ་མིའི་ཞིབ་འཇུག་གི་ དང་འདོད་ཚུའི་སྐུང་སྐྱོབ་འབད་ནིའི་དོན་ལུ་ གོང་འཕེལ་བཏང་ཡིན།

༡༣. ཟད་འགྲོ་སྤྱོད་ཚུལ་
ལས་འགྱུལ་འདི་གི་དོན་ལུ་ བཅའ་མར་གཏོགས་མི་ཚུ་ལུ་ དངུལ་གྱི་ཐོག་ལས་ཟད་འགྲོ་མེད། བཅའ་མར་གཏོགས་ནིའི་དོན་ལུ་ མ་དངུལ་བཞག་བཞགས་མེད།

༡༩. བསྒབ་སྟོན་མཐའ་བཅད།
ཞིབ་འཚོལ་པ་ཚུ་དང་འབྲེལ་བ་འཐབ་ཞིན་མ་ལས་ བཅའ་མར་གཏོགས་འདོད་ཡོད་པ་ཅིན་ འགན་ཡིག་འབྲི་ཤོག་ནང་མིང་རྟགས་བཀོད་ནི་ ཞིབ་འཚོལ་བ་ལུ་སྤྱོད་གནང་ཟིར་ ཞུ་ནི་ཡིན།

(ཞིབ་འཚོལ་པའི་འདྲ་བཤུས་)།།

English Consent Form III

Consent Form for the Parents or Legal Guardians (Participant's copy)

Full Project Title: Towards a spatial decision support system for malaria elimination in Bhutan
Lay Project Title: Use of geography information system in malaria elimination in Bhutan.

Principal Researchers:

Dr Kinley Wangdi, PhD student, School of Population Health, The University of Queensland

Prof Archie Clements, Professor of Infectious Disease Epidemiology, School of Population Health, The University of Queensland

Dr Michelle Gatton, Queensland University of Technology School of Public Health
Mr Gerard Kelly, School of Population Health, The University of Queensland

I have:

- read, or have had read to me, and I understand the Participant Information;
- freely agreed to allow my child to participate in this project according to the conditions in the Participant Information;
- had any questions or queries answered to my satisfaction;
- understood that the project is for the purpose of research and not for treatment;
- understood that the confidentiality of information will be maintained and safeguarded; and
- given permission for medical practitioners, other health professionals, and/or treating hospital, to release information concerning disease and treatment of my child which is needed for this research and understand that such information will remain confidential.

I will be given a copy of the Participant Information and Consent Form of my child to keep.

The researcher has agreed not to reveal the identity and personal details of my child if information about this project is published or presented in any public form.

Participant's Parent's Name (printed)

……..... Signature Date

Address……..……
……
……..…

Phone (Hm): …….. (Mb): ….…… (Wk): …….

Name of Witness to Participant's Signature (printed)…….

Signature Date

Note: All parties signing the Consent Form must date their own signature.

Consent Form (Researcher's copy)

Full Project Title: Towards a spatial decision support system for malaria elimination in Bhutan
Lay Project Title: Use of geography information system in malaria elimination in Bhutan.
Principal Researchers:

Dr Kinley Wangdi, PhD student, School of Population Health, The University of Queensland

Prof Archie Clements, Professor of Infectious Disease Epidemiology, School of Population Health, The University of Queensland

Dr Michelle Gatton, Queensland University of Technology School of Public Health
Mr Gerard Kelly, School of Population Health, The University of Queensland

I have:

- read, or have had read to me, and I understand the Participant Information;
- freely agreed to allow my child to participate in this project according to the conditions in the Participant Information;
- had any questions or queries answered to my satisfaction;
- understood that the project is for the purpose of research and not for treatment;
- understood that the confidentiality of information of my child will be maintained and safeguarded; and
- given permission for medical practitioners, other health professionals, and/or treating hospital, to release information concerning my child's disease and treatment which is needed for this research and understand that such information will remain confidential.

I will be given a copy of the Participant Information and Consent Form to keep.

The researcher has agreed not to reveal my identity and personal details if information about this project is published or presented in any public form.

Participant's Parent's Name (printed) …….....

Signature Date

Address…….
……
……

Phone (Hm): …….. (Mb): ….…… (Wk): ……

Name of Witness to Participant's Signature (printed)…….

Signature Date

Note: All parties signing the Consent Form must date their own signature.

REVOCATION OF CONSENT Form (Participant's copy)

Full Project Title: Towards a spatial decision support system for malaria elimination in Bhutan
Lay Project Title: Use of geography information system in malaria elimination in Bhutan.
Principal Researchers:

Dr Kinley Wangdi, PhD student, School of Population Health, The University of Queensland

Prof Archie Clements, Professor of Infectious Disease Epidemiology, School of Population Health, The University of Queensland

Dr Michelle Gatton, Queensland University of Technology School of Public Health
Mr Gerard Kelly, School of Population Health, The University of Queensland

I hereby wish to WITHDRAW my consent of my child to participate in the research proposal described above.

Name .....

Signature .....

Date ...../...../.....

Address .....

.....

.....

REVOCATION OF Consent Form (Researcher's copy)

Full Project Title: Towards a spatial decision support system for malaria elimination in Bhutan
Lay Project Title: Use of geography information system in malaria elimination in Bhutan.

Principal Researchers:

Dr Kinley Wangdi, PhD student, School of Population Health, The University of Queensland

Prof Archie Clements, Professor of Infectious Disease Epidemiology, School of Population Health, The University of Queensland

Dr Michelle Gatton, Queensland University of Technology School of Public Health
Mr Gerard Kelly, School of Population Health, The University of Queensland

I hereby wish to WITHDRAW my consent of my child to participate in the research proposal described above.

Name .....

Signature .....

Date ...../...../.....

Address .....

.....

.....

"I do not wish to take part" - Refusal of Consent Form (Participant's copy)

Full Project Title: Towards a spatial decision support system for malaria elimination in Bhutan
Lay Project Title: Use of geography information system in malaria elimination in Bhutan.

Principal Researchers:

Dr Kinley Wangdi, PhD student, School of Population Health, The University of Queensland

Prof Archie Clements, Professor of Infectious Disease Epidemiology, School of Population Health, The University of Queensland

Dr Michelle Gatton, Queensland University of Technology School of Public Health
Mr Gerard Kelly, School of Population Health, The University of Queensland

By returning this form you are showing that you do not wish your children to take part in this study.

Participant's Parent's Name (printed)

…….... Signature Date

"I do not wish to take part" - Refusal of Consent Form (Researcher's copy)

Full Project Title: Towards a spatial decision support system for malaria elimination in Bhutan
Lay Project Title: Use of geography information system in malaria elimination in Bhutan.

Principal Researchers:

Dr Kinley Wangdi, PhD student, School of Population Health, The University of Queensland

Prof Archie Clements, Professor of Infectious Disease Epidemiology, School of Population Health, The University of Queensland

Dr Michelle Gatton, Queensland University of Technology School of Public Health
Mr Gerard Kelly, School of Population Health, The University of Queensland

By returning this form you are showing that you do not wish your child to take part in this study.

Participant's parent's Name (printed)

…….... Signature Date

Dzongkha Consent Form III

ཞ་ཡིའི་ཁས་ལྡེན་ལན་འཛིན་རྟོག། (བཅའ་མར་གཏོགས་མིའི་འདུ་)

ལས་འགུལ་ཡོངས་རྫོགས་ཀྱི་མིང་: འབྲུག་ལུ་ཚོད་ནད་མ་ལ་རེ་ཡ་རུ་བསྒྲུབ་འབད་ནི་དོན་ལུ་ འཕེལ་ཡོད་མཐའ་བཅད་རྒྱུ་སྐྱོར་ལས་ལྷགས་མཐའ་དོན་ལུ། འབྲུག་ལུ་ཚོད་ནད་མ་ལ་རེ་ཡ་རུ་བསྒྲུབ་འབད་ནི་ མ་རིག་བརྡ་དོན་ལས་ལྷགས་བསྟར་སྤྱོད།

ཞིབ་འཚོལ་བ་གཙོ་ཅན་:

ཀུན་ལེགས་དབང་འདུས་ PhD སློབ་སྦྱིན། མེ་རྩོབས་འཛོད་བསྟེན་སློབ་གྲྭ་ ཀུ་ཕེནས་ལེནའི་གཞུག་ལག་སློབ་ཐེ།
ཚེ་སོག་ ལེགས་སྩར་བ་ ཚར་ཅེ་ ཀི་ལི་མེནཏེས། ནད་འབྱུང་ནང་འཕེལ་ཡོད་ལེགས་སྩར་བ། མེ་རྩོབས་འཛོད་བསྟེན་སློབ་གྲྭ་ ཀུ་ཕེནས་ལེནའི་གཞུག་ལག་སློབ་ཐེ།
མའི་ཀ་ལེ་ ག་ཏོན།
ཇི་ཨའི་ཀེ་ལེ། མེ་རྩོབས་འཛོད་བསྟེན་སློབ་གྲྭ་ ཀུ་ཕེནས་ལེནའི་གཞུག་ལག་སློབ་ཐེ།

ང་ཚོས་:

- འདི་རྟྭག་ཞིན་ལས་ ཡང་ན་ གཞན་ཚོས་ དེའི་དོན་ལུ་རྟྭག་ཞིནམ་ལས་ དེའི་ཚ་ལོ་བཅའ་མར་གཏོགས་མའི་བརྡ་དོན་རྩོ་ལེགས་ཨོམ་སྒེ་ཀ་ གོ་ཡི།
- བཅའ་མར་གཏོགས་མའི་བརྡ་དོན་ནང་འཁྱེལ་ཏེ་ ལས་འགུལ་འདི་ནང་ རང་རོས་ཐོག་ལས་ བཅའ་མར་གཏོགས་ནི་ཚེན།
- དུ་བ་ཡོད་མི་རྩྭ་ ང་རང་གི་རྩྭ་ཆོམ་ནང་ཕྱན་ཐོག་ལས་ ལན་ཐོབ་ཅི།
- ལས་འགུལ་འདི་ སྤྱན་བཙོས་ཀྱི་དོན་ལུ་མེན་པར་ ཞིབ་འཚོལ་ཀྱི་དོན་ལུ་ཚེནམ་ཀ་གོ་ཡི།
- བརྡ་དོན་ཚུ་གསང་བའི་ཐོག་ལུ་ ཉེན་སྐྱང་ནང་ཕྱན་སྒེ་བཞག་ནི་ཚེནམ་ཀ་གོ་ཡི།
- གནང་བའི་ཐོག་ལས་ གསོ་བའི་ལག་ལེན་བ་ཡང་ གཞན་འཛོད་བསྟེན་ཁྱད་རིག་གི་ལུ་འབད་མི་ དེ་ལས་ སྤྱན་ཁང་ནང་སྤྱན་བཙོས་འབད་མི་ཚུ་ལུ་ འཕེལ་ཡོད་ནང་གཞི་སྐོར་ སྤྱན་བཙོས་འབད་ནི་དགོས་དོན་ནང་འཁྱེལ་ཏེ་ ཞིབ་འཚོལ་འབད་ནི་ཚེ་ཐོག་ལས་ ཁ་གོ་ཡི།

ངའི་ཚ་ལོ་ལུ་ ཧང་ངང་གཅིག་ཁར་བཞག་ནི་དོན་ལུ་ བཅའ་མར་གཏོགས་ནི་འཛོད་དོན་ནང་ཁས་ལན་འཕྲི་ཨོག་འཕེབ།

ཞིབ་འཚོལ་བ་གིས་ ལས་འགུལ་གི་བརྡ་དོན་ཚུ་ དེའ་བསྒྲུན་ངང་གསལ་སྟོན་འབད་དགོ་པ་ཅིན་ ངའི་ངོ་སྟོན་ཚུ་ གསལ་སྟོན་མི་འབད་ནིའི་ཁ་འཚམ་ཅི།

བཅའ་མར་གཏོགས་མི་ཚ་ལོའི་ཡིག་ཅོཏིང་ (པར་བསྒྲུན་)

..... མིང་རྟགས་

ཚོས་

ཁ་བྱང་.....

.....

.....

..... བརྒྱུད་འཕྲིན་ཨང་ (Hm): ..... (Mb):

..... (Wk): .....

བཅའ་མར་གཏོགས་མིའི་དཔང་ཡིའི་མིང་དང་མིང་རྟགས་(པར་བསྒྲུན)..... མིང་རྟགས་

ཚོས་

དྲན་བསྐུལ་: རྟ་ཁཅ་གང་ཡིས་ མིང་རྟགས་བཀོད་པའི་ཚོས་གང་ངེས་པར་དུ་བཀོད་དགོ

ཁས་ལན་འབྲི་རྒྱ། (ཞིབ་འཚོལ་པའི་འདུ་)

ལས་འགུལ་ཡོངས་རྫོགས་ཀྱི་མིང་: འབྲུག་ལུ་ཚད་ནད་མ་ལ་རི་ཡ་རུ་བསྐྱད་འབད་ནས་ཀྱི་དོན་ལུ་ འཇིལ་ཡོད་མཐའ་བཅད་བཏང་རྒྱབ་སྐྱོར་ལམ་ལུགས་མཐའ་དོན་ལུ། འབྲུག་ལུ་ཚད་ནད་མ་ལ་རི་ཡ་རུ་བསྐྱད་འབད་ནས་ཀྱི་ ས་རིག་བརྡ་དོན་ལམ་ལུགས་བསྟུར་སྦྱོང་།

ཞིབ་འཚོལ་བ་གཙོ་ཅན:

ཀུན་ལེགས་དབང་འདུས་ PhD སློབ་ཕྲུག། མེ་རྟོགས་འཛོད་བསྟེན་སློབ་གྲྭ་ ཀུ་ཤེནས་ལེནྡེ་གཙུག་ལག་སློབ་སྡེ།
ཚེ་སོག་ ལེགས་སྩར་བ་ ཚར་ཅི་ ཀི་ལི་ཆེནཏིས། ནང་འབྲུབ་ནང་འཛེལ་ཡོད་ལེགས་སྩར་བ། མེ་རྟོགས་འཛོད་བསྟེན་སློབ་གྲྭ་ ཀུ་ཤེནས་ལེནྡེ་གཙུག་ལག་སློབ་སྡེ།
མའི་ཀ་ལེ་ གཱ་དོ་ནྡ།
ཇེ་རཉི་ཀེ་ལེ། མེ་རྟོགས་འཛོད་བསྟེན་སློབ་གྲྭ་ ཀུ་ཤེནས་ལེནྡེ་གཙུག་ལག་སློབ་སྡེ།

ང་ཚོས:

- འདི་སྐྱག་ཞིན་ལས་ ཡང་ན་ གཞན་གིས་ དེའི་དོན་ལུ་སྐྱག་ཞིན་མ་ལས་ ང་ཚོས་བཅའ་མར་གཏོགས་མའི་བརྡ་དོན་ཚུ་ལེགས་ཤོམ་སྦེ་ཤེས་ཡོ་ཁ་ཐོ་ཡི།
- བཅའ་མར་གཏོགས་མའི་བརྡ་དོན་དང་འཁྲིལ་ཏེ་ ལས་འགུལ་འདི་ནང་ རང་མོས་ཐོག་ལས་དེའི་ཚ་ལོ་ བཅའ་མར་གཏོགས་ནི་ཞིན།
- ཏུ་ག་ཡོད་མི་ཚུ་ ང་རང་གི་བློ་ཚོམ་དང་ལྡན་ཐོག་ལས་ ལན་ཐོབ་ཨི།
- ལས་འགུལ་འདི་ སྐབས་བཅོས་ཀྱི་དོན་ལུ་མེན་པར་ ཞིབ་འཚོལ་ཀྱི་དོན་ལུ་ཞིན་མ་ཁ་གོ་ཡི།
- དེའི་ཚ་ཡོའི་བརྡ་དོན་ཚུ་གསང་བའི་ཐོག་ལུ་ ཉེན་སྐྱང་དང་ལྡན་སྦེ་བཞག་ནི་ཞིན་མ་ཁ་གོ་ཡི།
- གནང་བའི་ཐོག་ལས་ གསོ་བའི་ལག་ལེན་ཁ་དང་ གཞན་འཛོད་བསྟེན་ཁྲུད་རིག་གི་ལུ་འབད་མི་ རེ་ལས་ སྐབས་ཁང་ནང་སྐབས་འབད་མི་ཚུ་ལུ་ དེའི་ཚ་ཡོའི་ནང་གཞི་སྒོར་ སྐབས་བཅོས་འབད་ནི་ དོན་དང་འཁྲིལ་ཏེ་ ཞིབ་འཚོལ་འབད་ནི་དང་ གསང་བའི་ཐོག་ལུ་བཞག་ནི་ཞིན་མ་ཁ་གོ་ཡི།

ང་ལུ་ རང་དང་གཅིག་ཁར་བཞག་ནིའི་དོན་ལུ་ བཅའ་མར་གཏོགས་ནིའི་བརྡ་དོན་དང་ལས་ལན་འདི་ཨོ་ཁ་བཏང་།

ཞིབ་འཚོལ་བ་གིས་ ལས་འགུལ་གི་བརྡ་དོན་ཚུ་ དེའི་བསྐྱན་དང་གསལ་སྟོན་འབད་དགོ་པ་ཅིན་ དེའི་ངོ་སྤྲོད་དང་ང་རང་གི་ཁ་གསལ་ཚུ་ གསལ་སྟོན་མེ་འབད་ནིའི་ཁ་འཆམ་ཅི།

བཅའ་མར་གཏོགས་མི་ཚ་ཡོའི་ཁམ་ཀྱི་ངོ་མིང་ (ཁར་བསྐྱན་)

..... མིང་རྟགས་

ཚེས་

ཁ་བྱང་.....

.....

.....

..... བརྒྱུད་འཛིན་ཚང (Hm): ..... (Mb):

..... (Wk): .....

བཅའ་མར་གཏོགས་མིའི་དཔང་ཡིའི་མིང་དང་མིང་རྟགས་(ཁར་བསྐྱན)..... མིང་རྟགས་

ཚེས་

དྲན་བསྐུལ་: རྩལཁག་ར་ཡིས་ མིངརྟགས་ཁོོད་པའི་ཚེས་གྲངས་འབྲི་དགོ་དགོ།

ཁས་ལན་དགོངས་ཞུའི་འཕྲི་ཐོག (བཅའ་མར་གཏོགས་མིའི་འདུ)

ལས་འགུལ་ཡོངས་རྫོགས་ཀྱི་མིང་: འབྲུག་ལུ་ཚང་ནད་མ་ལ་རི་ཡ་རྩ་བསྐྱང་འབད་ནི་དོན་ལུ་ འབྲེལ་ཡོད་མཐའ་བཅད་བཅད་རྒྱབ་སྐྱོར་ལམ་ལུགས་མཐའ་དོན་ལུ། འབྲུག་ལུ་ཚང་ནད་མ་ལ་རི་ཡ་རྩ་བསྐྱང་འབད་ནི་ ས་རིག་བརྟ་དོན་ལམ་ལུགས་བསྟར་སྤྱོད།

ཞིབ་འཚོལ་བ་གཙོ་ཅན:

ཀུན་ལེགས་དབང་འདུས་ PhD སློབ་ཁྲག། མི་རློབས་འཛོད་བསྟེན་སློབ་གྲྭ་ ཀུ་ཤེནི་ལེནྡི་གཙུག་ལག་སློབ་སྡེ།
ཚེ་སོག་ ལེགས་སྦྱར་བ་ ཚར་ཅི་ ཀེ་ལི་མེནཏིས། ནད་འབྱབ་ནད་འཛེལ་ཡོད་ལེགས་སྦྱར་བ། མི་རློབས་འཛོད་བསྟེན་སློབ་གྲྭ་ ཀུ་ཤེནི་ལེནྡི་གཙུག་ལག་སློབ་སྡེ།
མའི་ཀ་ལེ་ ཀ་ཏོན།
ཇི་རའི་ཀེ་ལེ། མི་རློབས་འཛོད་བསྟེན་སློབ་གྲྭ་ ཀུ་ཤེནི་ལེནྡི་གཙུག་ལག་སློབ་སྡེ།

ང་རང་གིས་ དང་འདོད་དང་འཁྲིལ་ཏེ་ གོང་གསལ་ངེའི་ཚ་ཚོ་ཞིབ་འཚོལ་གྲོས་ལན་ལས་དགོངས་ཞུ་ནི་ཨིནམ་ལས་ དགོངས་ཞུ་འདི་གིས་ ང་རང་གི་སྐན་བཙོས་དང་ སྐན་བཙོས་འབད་མི་ ཚུའི་འབྲེལ་བ་ལུ་མི་གནོད་པའི་ངོས་ལེན་ལུ་

ཚ་ཚོའི་ཁཐ་ཀྱི་མིང་.....

.....མིང་རྟགས་

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..... ཚེས་ ...../...../.....

ཁ་བྱང་

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ཁས་ལན་དགོངས་ཞུའི་འབྲི་རྟོག་ (ཞིབ་འཚོལ་པའི་འདྲ་)

ལས་འགྲུལ་ཡོངས་རྫོགས་ཀྱི་མིང་: འབྲུག་ལུ་ཚད་ནད་མ་ལ་རི་ཡ་རྩ་བསྐྱང་འབད་ནི་དོན་ལུ་ འཕེལ་ཡོད་མཐའ་བཅད་རྒྱབ་སྐྱོར་ལམ་ལུགས་མཐའ་དོན་ལུ། འབྲུག་ལུ་ཚད་ནད་མ་ལ་རི་ཡ་རྩ་བསྐྱང་འབད་ནི་ ས་རིག་བརྡ་དོན་ལམ་ལུགས་བསྟར་སྦྱོང་།

ཞིབ་འཚོལ་བ་གཙོ་ཅན:

ཀུན་ལེགས་དབང་འདུས་ PhD སློབ་ཁུག། མི་རྟོགས་འཛོད་བསྟེན་སློབ་གྲྭ་ ཀུ་ཤེནི་ལེནྡྲི་གཙུག་ལག་སློབ་སྡེ།
ཚེ་སོག་ ལེགས་སྩར་བ་ ཚར་ཅི་ ཀེ་ལེ་མེནྡ་ཏེས། ནད་འབྲུབ་ནང་འཛེལ་ཡོད་ལེགས་སྩར་བ། མི་རྟོགས་འཛོད་བསྟེན་སློབ་གྲྭ་ ཀུ་ཤེནི་ལེནྡྲི་གཙུག་ལག་སློབ་སྡེ།
མའི་ཀ་ལེ་ གཱ་ཏོན།
ཇི་རའྀ་ཀེ་ལེ། མི་རྟོགས་འཛོད་བསྟེན་སློབ་གྲྭ་ ཀུ་ཤེནི་ལེནྡྲི་གཙུག་ལག་སློབ་སྡེ།

ང་རང་གིས་ དང་འདོད་དང་འབྲེལ་ཏེ་ གོང་གསལ་ཡིའི་ཞུ་ཡི་ཞིབ་འཚོལ་སློས་འཚར་གྱི་ལས་ལན་ལས་དགོངས་ཞུ་ནི་ཨིནམ་ལས་ དགོངས་ཞུ་འདི་གིས་ ང་རང་གི་སྨན་བཅོས་དང་སྨན་བཅོས་འབད་མི་ཚུའི་འབྲེལ་བ་ལུ་མི་གནོད་པའི་ངོས་ལེན་ལུ་

ཞ་ཡིའི་ཐམ་ཀྱི་མིང་.....

.....མིང་རྟགས་

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..... **ཚེས་** ...../...../.....

ཁ་ཟྲུང་

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“ང་བཅའ་མར་གཏོགས་འདོད་ཨེད་” – ལས་ལན་འཁྲི་ཤོག་ངོས་ཨེད། (བཅའ་མར་གཏོགས་མིའི་འདུ)

ལས་འགུལ་ཡོངས་རྫོགས་ཀྱི་མིང་: འབྲུག་ལྷ་ཚང་ནང་མ་ལ་རི་ཡ་རྩ་བསྒང་འབབ་ནི་དོན་ལྷ་ འཁེལ་ཡོད་མཐའ་བཅད་རྒྱབ་སྐྱོར་ལམ་ལྷགས་མཐའ་དོན་ལྷ། འབྲུག་ལྷ་ཚད་ནང་མ་ལ་རི་ཡ་རྩ་བསྒང་འབབ་ནི་ ས་རིག་བརྡ་དོན་ལམ་ལྷགས་བསྟར་སྐྱོང།

ཞིབ་འཚོལ་བ་གཙོ་ཅན་:

ཀུན་ལེགས་དབང་འདུས་ PhD སློབ་སྒྲུག། མི་རློབས་འཛོད་བསྟེན་སློབ་གྲྭ་ ཀུ་ཤེནས་ལེནའི་གསྒྲུག་ལག་སློབ་ཐེ།
ཚེ་སོག་ ལེགས་སྒྲུར་བ་ ཚར་ཅི་ ཀི་ལི་མེནའིས། ནང་འབྲུབ་ནང་འཁེལ་ཡོད་ལེགས་སྒྲུར་བ། མི་རློབས་འཛོད་བསྟེན་སློབ་གྲྭ་ ཀུ་ཤེནས་ལེནའི་གསྒྲུག་ལག་སློབ་ཐེ། མའི་ཀ་ལེ་ གཱ་ཏོན།
ཇི་རའི་ཀེ་ལེ། མི་རློབས་འཛོད་བསྟེན་སློབ་གྲྭ་ ཀུ་ཤེནས་ལེནའི་གསྒྲུག་ལག་སློབ་ཐེ།

འབྲི་ཨོག་ལོག་སྒྲུད་མི་དེ་ ཞིབ་འཇུག་ནང་ཚ་ལོ་ཚུ་ཞིབ་འཚོལ་ནང་བཅའ་མར་གཏ་ གས་ནི་དང་འདྲིད་མེད་པའི་ངོས་འཛིན་འབད་ཁ་མེན།

བཅའ་མར་གཏོགས་མིའི་ཚ་ལོའི་ཐན་ཀྱི་ངོ་མིང་ (པར་བསྒྲིན་)

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མིང་རྟགས་དང་ཚེས་

“ང་བཅའ་མར་གཏོགས་འདོད་མེད་” – ལས་ལན་འཐེའི་ཤོག་ངོས་མེད། (ཞིབ་འཚོལ་པའི་འདྲ)

ལས་འགུལ་ཡོངས་རྫོགས་ཀྱི་མིང་: འབྲུག་ལྗོངས་ཚད་ནད་མ་ལ་རེ་ཡ་རྩ་བསླབ་འབད་ཞིའི་དོན་ལུ་ འཕེལ་ཡོད་མཐའ་བཅད་རྒྱབ་སྐྱོར་ལམ་ལུགས་མཐའ་དོན་ལུ། འབྲུག་ལྗོངས་ནད་མ་ལ་རེ་ཡ་རྩ་བསླབ་འབད་ཞིའི་ ས་རིག་བརྡ་དོན་ལམ་ལུགས་བསྟར་སྦྱོང་།

ཞིབ་འཚོལ་བ་གཙོ་ཅན་:

ཀུན་ལེགས་དཔང་འདུས་ PhD སློབ་སྟུག། མི་རྣོབས་འཛོད་བསྟེན་སློབ་གྲྭ་ ཀུ་ཤེནས་ལེན་ཀྱེ་གཙུག་ལག་སློབ་སྡེ། ཚེ་སོག་ ལེགས་སྩུར་བ་ ཚར་ཅེ་ ཀེ་ལི་མེནཊ་ཀེསི། ནད་འབྱབ་ནང་འཕེལ་ཡོད་ལེགས་སྩུར་བ། མི་རྣོབས་འཛད་བསྟེན་སློབ་གྲྭ་ ཀུ་ཤེནས་ལེན་ཀྱེ་གཙུག་ལག་སློབ་སྡེ། མའི་ཀ་ལེ་ ཀ་ཏོན།
ཇི་ར་ཏི་ཀེ་ལེ། མི་རྣོབས་འཛོད་བསྟེན་སློབ་གྲྭ་ ཀུ་ཤེནས་ལེན་ཀྱེ་གཙུག་ལག་སློབ་སྡེ།

འཕྲི་ཐོག་ལོག་སྤྲོད་མི་དེ་ ཞིབ་འཚུག་ནང་འདིའི་ཚ་ལོ་ཚུ་བཅའ་མར་གཏོགས་ནི་དང་འདོད་མེད་པའི་ངོས་འཛིན་འབད་ཁ་ཤིན།

བཅའ་མར་གཏོགས་མིའི་ཚ་ལོའི་ཤག་ཀྱི་ངོ་མིང་ (བར་བསྟུན་)

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མིང་རྟགས་དང་ཚེས་

English Information Sheet IV

Participant information sheet

Researcher:

My name is Dr. Kinley Wangdi, I am PhD student of Research School of Population Health under the College of Medicine, Biology and Environment, Australian National University.

Project Title: Evaluation of spatial decision support system in malaria control activities in Bhutan through key informant interview

General Outline of the Project:

- **Description and Methodology:** The purpose of this project is to determine whether the new tool namely spatial decision support system (SDSS) which was used for malaria control and prevention in Bhutan in last six months was useful or how you felt regarding SDSS and observe how you go about conducting SDSS for different malaria control and preventive activities. The usefulness and other benefits will be determined through discussion. This will involve discussion and answering some question. I will record the discussion for analysis at a later date and take photographs and field notes to aid me analysing with your consent.

- **Participants:** The participants for the study will be the officials from the Vector-borne disease control programme (VDCP), Department of Public Health (DoPH), Ministry of Health (MoH), Bhutan and district malaria supervisors (DMS) and malaria technicians (MT). A total of 12 participants will be recruited for the research.

- **Use of Data and Feedback:** The data obtained through the research will be used for the PhD thesis. The findings could be published as part of the PhD thesis. The feedback of the findings and result will be shared with the Research Ethics Board of Health (REBH), Bhutan, VDCP and with participants (if participants request to know the result).

Participant Involvement:

- **Voluntary Participation & Withdrawal:** Participation in the project is **voluntary** and you may, without any penalty, decline to take part or withdraw

from the research at any time until the work is prepared for publication without providing an explanation, or you can refuse to answer a question. In the event you decide to withdraw, data drawn from you during the discussion will be destroyed and will not be used for analysis and subsequent research.

- **What will participants have to do?** You will be required to discuss your experience in the use of SDSS for the malaria control and preventive activities. The discussion will be audio-recorded with your approval and consent. The recordings will be used only by the researchers directly involved in the research. They include my PhD supervisors from ANU and external advisors

- **Location and Duration:** The research will take place in the secured room in the health center you work and the expected time of interview will last around one hour and interview will be done only once and no further follow up interviews will be conducted.

Confidentiality:

- **Confidentiality:** The information obtained through the research will be used only by the researchers including the student and two supervisors from ANU. They include me and my PhD supervisors. During the interview, it will be conducted in the secured room in the health center you work. The purpose of the meeting will not be disclosed to any other staff than you. Utmost care will be taken not to include any personal information in the results and in the publication. Your name will be coded which be known only by the aforementioned researchers. However, if you so desires to include your name in the results publication, your wishes will be respected and included in relevant sections. Photography will be taken to see how you work implementing SDSS. However, you will not be exposed in the publication, the aim of taking photography is to aid the researcher in drawing the pictures to show the ethnography study.

Data Storage:

- **Where:** The data will be stored electronically at the Research School of Population Health, ANU. The data will be stored in the computer and secured through password of the computer, which will be known only to the student. The personal information will not be included in data collection so that confidentiality of information will be maintained.

- **How long:** The information obtained from you will be stored for a period of at least five years from publication or following the submission of my PhD thesis.

- **Destruction of Data:** At the end of the storage period, the data will be destroyed.

Queries and Concerns:

- **Contact Details for More Information:** If you want to have any queries on the project. You can contact me, my PhD advisors or the ANU ethical officer at:
    - **Dr. Kinley Wangdi** (Primary researcher), PhD Student, National Center for Epidemiology and Population Health (NCPH), Research School of Population Health (RSPH), ANU, email address: kinley.wangdi@anu.edu.au, Phone No. +61-410470143
    - **Prof Archie Clements** (Primary supervisor), Director, RSPH, ANU, email address: director.rsph@anu.edu.au, Phone No. + 61 2 61254578
    - **Assoc Prof Cathy Banwell**,(Supervisor), NECPH, RSPH, email address: cathy.banwell@anu.edu.au, Phone No. +61 2 6125 0016

- **Overseas Contacts (if relevant):** The local Contact person's address:
    - **Chief Programme Officer,** VDCP, DoPH, MoH, Bhutan, email address: rinzin69@yahoo.com.

Ethics Committee Clearance:

The ethical aspects of this research have been approved by the ANU Human Research Ethics Committee. If you have any concerns or complaints about how this research has been conducted, please contact:

Ethics Manager
The ANU Human Research Ethics Committee
The Australian National University
Telephone: +61 2 6125 3427
Email: Human.Ethics.Officer@anu.edu.au

Australian National University

English Consent Form V

Written Consent for Participants

Evaluation of spatial decision support system in malaria control activities in Bhutan through key informant interview

I have read and understood the Information sheet you have given me about the research project, and I have had any questions and concerns about the project addressed to my satisfaction. I agree to participate in the project.

Signature:……

Date:…../……/2015 (dd/mm/year)

YES ☐ NO ☐ I agree to this interview being audio taped

YES ☐ NO ☐ I agree to have photographs taken and used in the research

YES ☐ NO ☐ I agree to have field notes taken by the researcher

I agree to be identified in the following way

YES ☐ NO ☐ Full name

YES ☐ NO ☐ Complete confidentiality

Signature:……

Date:…./……/2015 (dd/mm/year)

Australian National University

Dzongkha Consent Form V

འབྲུག་ལུ་ ཚད་ནད་སྨུ་ལ་དེ་ཡ་ བཀག་ཐབས་ཀྱི་ལས་སྡུ་དང་འཁེལ་བའི་ རྒྱབ་སྐྱོར་ལམ་ལུགས་ཀྱི་དོན་ལུ་ བཅའ་མར་གཏོགས་མིའི་ཚུའི་ གསང་བའི་ དྲི་བ་དྲིས་ལན་གྱི་དཔེ་དཔྱད་ ཡིག་ཐོག་ལས་ལེན།

ངགིས་ ཞིབ་འཚོལ་ལས་འགུལ་གྱི་དོན་ལུ་ བརྟ་དོན་ཡི་གུ་ཚུ་ ལྟག་ཞིནམ་ལས་ ལས་འགུལ་གྱི་སྐོར་ལས་ དྲི་བ་ཚུ་ ངགིས་ བསམ་པ་རྫོགས་ཏོག་ཏོ་སྟེ་ར་ ཏ་གོ་ཡི། ངགིས་ ལས་འགུལ་ནང་ བཅའ་མར་གཏོགས་ནི་འབས་ལེན་ཡོད།

མིང་རྟགས་:.....

ཟླ་ཚེས་:...../...../২০১৫ (ཟླ་ཚེས་/ཟླ་ཟླ་/ཟླ་ལོ་)

སྐུ་བཟུང་འཁོར་ལོ་ནང་ སྐུ་བཟུང་ཐོག་ལས་ དྲི་བ་དྲིས་ལན་འབད་ནི་ ངལ་རོས་ལེན་ཡོད། བཏུབ་☐ མི་བཏུབ་☐
པར་ཚུ་བཏབ་ཞིནམ་ལས་ ཞིབ་འཚོལ་ནང་ལག་ལེན་འཐབ་ནི་ ངལ་རོས་ལེན་ཡོད། བཏུབ་☐ མི་བཏུབ་☐
སྣ་ཁོངས་ནང་ ཞིབ་འཚོལ་པ་ཚུ་གིས་ ཟིན་ཐོ་བཀོད་ནི་ ངལ་རོས་ལེན་ཡོད། བཏུབ་☐ མི་བཏུབ་☐

ངགིས་ གཤམ་གསལ་རོས་འཛིན་འབད་ནི་རོས་ལེན་ཡོད།
རོ་མིངཡོངས་རྫོགས། བཏུབ་☐ མི་བཏུབ་☐
ཉེལ་ཡོད་གསང་བའི་ཐོག། བཏུབ་☐ མི་བཏུབ་☐

མིང་རྟགས་:.....

ཟླ་ཚེས་:...../...../২০১৫ (ཟླ་ཚེས་/ཟླ་ཟླ་/ཟླ་ལོ་)

APPENDIX 5

STANDARD OPERATING PROCEDURE (SOP) FOR SELECTION OF PARTICIPANTS FOR ASYMPTOMATIC MALARIA CARRIER STUDY

1. Purpose

This document provides general information on choosing the participants for testing their blood for asymptomatic malaria using the rapid diagnostic test (RDT) for diagnosing malaria.

2. Scope

2.1 Asymptomatic malaria is common in people residing in malaria endemic areas. Asymptomatic carriers are rarely detected through passive reporting system since these individuals will not exhibit any signs and symptoms like the symptomatic patients. However, these individuals can serve as a source of malaria infection for onward transmission. In order to detect asymptomatic carriers, active blood examination will be performed in inhabitants of Umling and Chuzergang in Sarpang district and Jomotshangkha and Samdrup Choling in Samdrup Jongkhar district.

2.2 The adult male members of all households will be line listed and each member will be assigned a number. Similarly adult females, and male and female children, will be line listed and assigned a number. Then the number will be chosen randomly (using numbered pieces of paper in a bag) for each group to select one adult male, one adult female, one male child and one female child. Incase if there is no male members present during the survey, an additional female will be chosen to make up four participants per household. This will also apply for other groups (adult female, male children and female children).

2.3 The aims and objectives of the study will be explained to the selected members of the household in the language they understood. They will be given time to question any doubts if they had any. After that informed consent form will be signed by the adults while for the children the informed consent will be obtained from parents or guardians.

2.4 The testing of the blood will be done by following the SOP for RDT.

3. Interpretation of results

3.1 The results will be made known to the participants.

3.2 The participants with blood test positive for *Plasmodium* will be referred to the nearest health center for the treatment.

3.2 The blood slide thick and thin slides will be made for the individual with positive RDT result for microscopic examination in the nearest health center.

Standard operating procedure of rapid diagnostic test (RDT)

1. Purpose

1.1 Using a Rapid Diagnostic Test (RDT), the *CareStart*™ Malaria HRP2/pLDH Combo Test, to detect circulating *Plasmodium falciparum* antigens and an antigen that is common to all four species of malaria, *Plasmodium falciparum* (*P.f.*), *Plasmodium vivax* (*P.v.*), *Plasmodium ovale* (*P.o.*) and *Plasmodium malariae* (*P.m.*) in whole blood.

2. Scope

2.1 The RDT uses two antibodies that are immobilized in two lines across the test strip. One antibody is pan specific to lactate dehydrogenase (pLDH) *P.f, P.v, P.m* and *P.o.* The other consists of a monoclonal antibody specific to Histidine-Rich Protein 2

(HRP2) of *P.f.* A procedural control line is also immobilized across the test strip and will always appear if the test has been performed correctly.

2.2 Briefly the procedure involves applying 5 µl of whole blood to the **sample well**. Two drops of assay buffer are added to the **buffer well**. Three colored lines may appear (as per Figure 1 below) resulting in:

1. A negative reaction of one band in the control area,

2. A P. f positive reaction three color bands (control, 2 and 1 areas) or two bands (one in the control area and another in area 1).

3. A mixed infection of three color bands (control, 2 and 1 areas): This could indicate P.f. only.

4. A positive reaction to *P.v, P.m* or *P.o* of two colored bands (control and area 2).

An invalid test is indicated when no colored band appears in the control area.

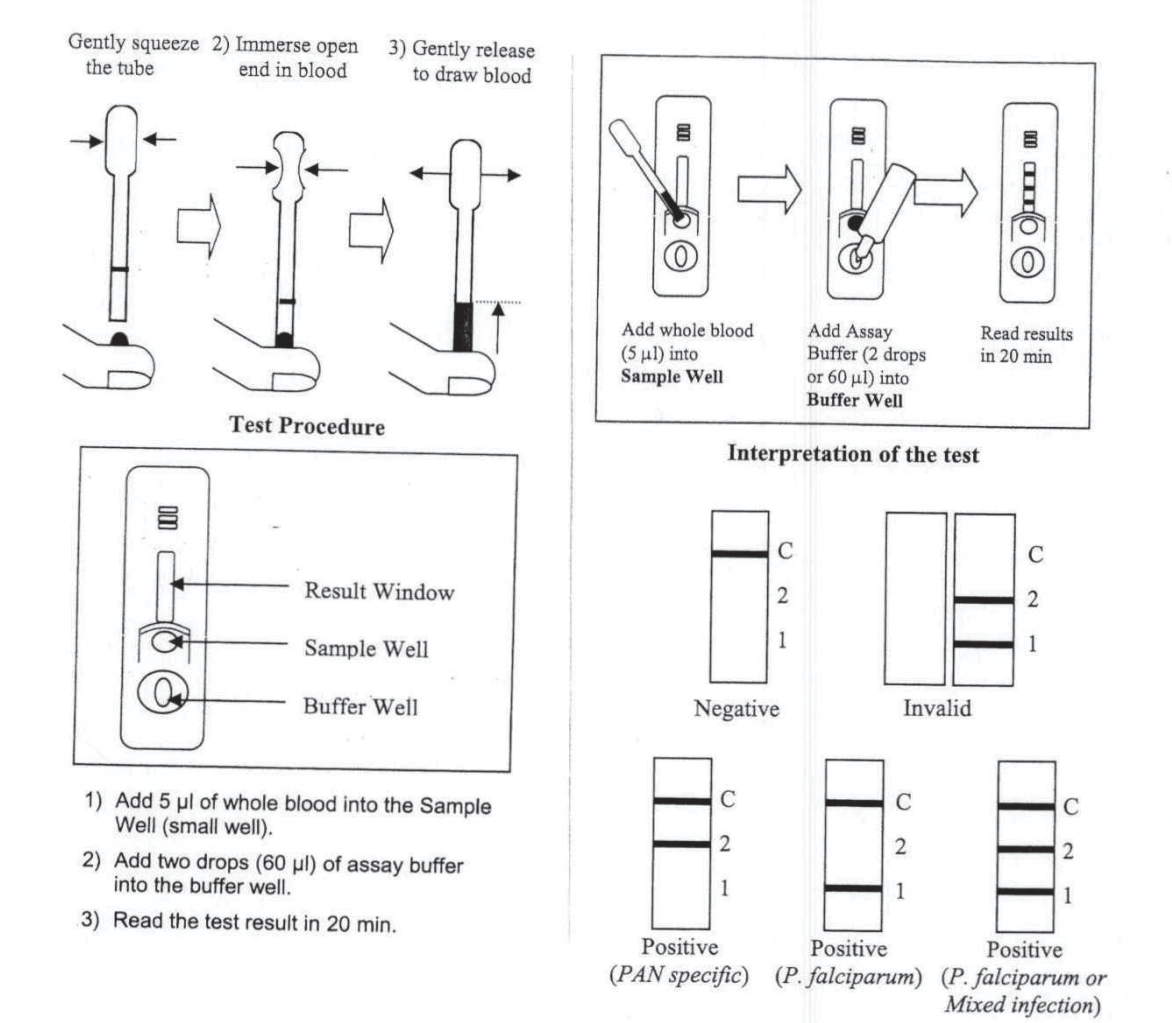


Figure 1: RDT process and reading results.

3. References

3.1 Manufacturer's instruction: Insert for *CareStart*™ Malaria HRP2/pLDH Combo Test.

4. Procedure

4.1 Refer to Figure 1 above for illustration of the procedure. Using a pipette collect 5 µl of capillary blood. To obtain capillary blood via puncture of a finger, heel or other appropriate site, cleanse the area with a sterile swab and dry with a sterile pad. Use a lancet to puncture the skin and collect the blood directly into the pipette. **Use the blood immediately.**

4.2 Ensure all test components are at room temperature prior to use. Just prior to use, remove the cassette from foil pouch. After puncturing an accessible site (eg. finger or heel) using the pipette provided or an automatic micropipette to collect the 5 µl of blood. Touch the tip of the pipette to the blood spot and gently suck up the blood to the 1st (5 µl) line on the pipette.

4.3 Transfer blood to the test cassette by touching the nozzle to the small **sample well** and gently squeezing the pipette bulb.

4.4 Holding the Assay Buffer bottle vertically, slowly add **2 drops (or 60µl)** of Buffer to the **large round** well.

4.5 Allow the reaction to proceed for **20 minutes**.

4.6 Read the results through the viewing window immediately at **20 minutes**. Refer to the details given in the insert for test interpretation. Results read after 20 minutes may be inaccurate and should not be reported.

4.7 Do not use kits beyond their expiration date. Keep storage boxes dry.

4.8 Store kits at 4°C - 37°C. **DO NOT FREEZE.**

5. Results interpretation

5.1 The following illustrations show how to interpret the results of the RDT.

Invalid: The test is invalid if the Control line (C) does not appear whether or not a

Test line (T) is present. If this occurs, the test should be repeated (if possible) using a new cassette.

5.2 Recording the results

The results should be recorded in the Table below.

Sample Number	Time started	Time Reading	Operator Name	Line 1 Control	Line 2 *P. falciparum*	Line 3 Pan	Interpretation
1	9:20	9:35	A	3	1	2	P.f. or mixed
2			A	4	1	2	P.f. or mixed
3			A	3	3	4	P.f. or mixed
4			B	0	2	0	Invalid
5			B	0	0	3	Invalid
6			C	3	0	2	P. v or P.m or P.o
7							

6. Storage condition

6.1 The used RDTs should be stored at room temperature and transported back to AMI in the bags provided. The RDTs can be used to extract DNA which can then be used to PCR amplify parasite DNA to confirm Plasmodium species.

7. Safety aspects

7.1 Appropriate PPE must be used and/or worn to reduce the risks associated with handing potentially infectious substances.

APPENDIX 6 SUPPLEMENTARY MATERIAL FROM PUBLICATION

THE LANCET Global Health

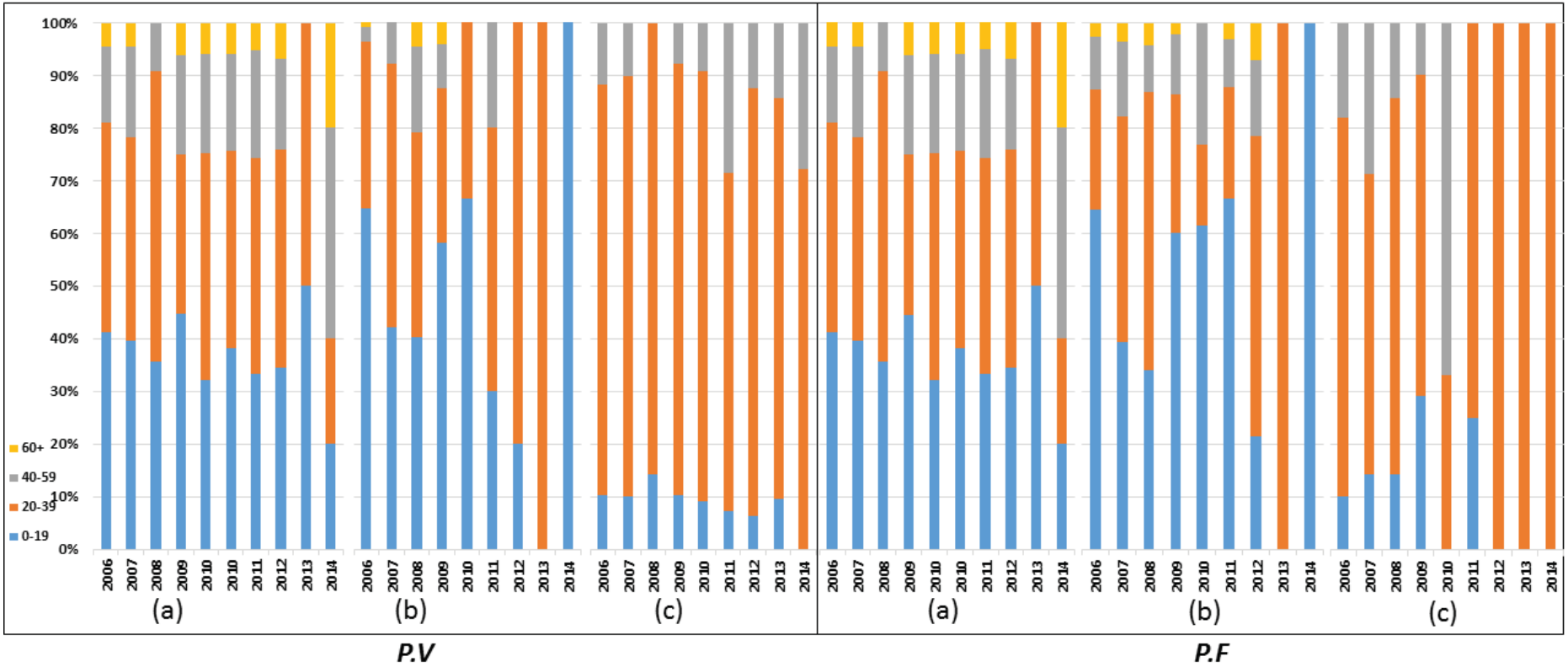
Supplementary appendix

This appendix formed part of the original submission and has been peer reviewed. We post it as supplied by the authors.

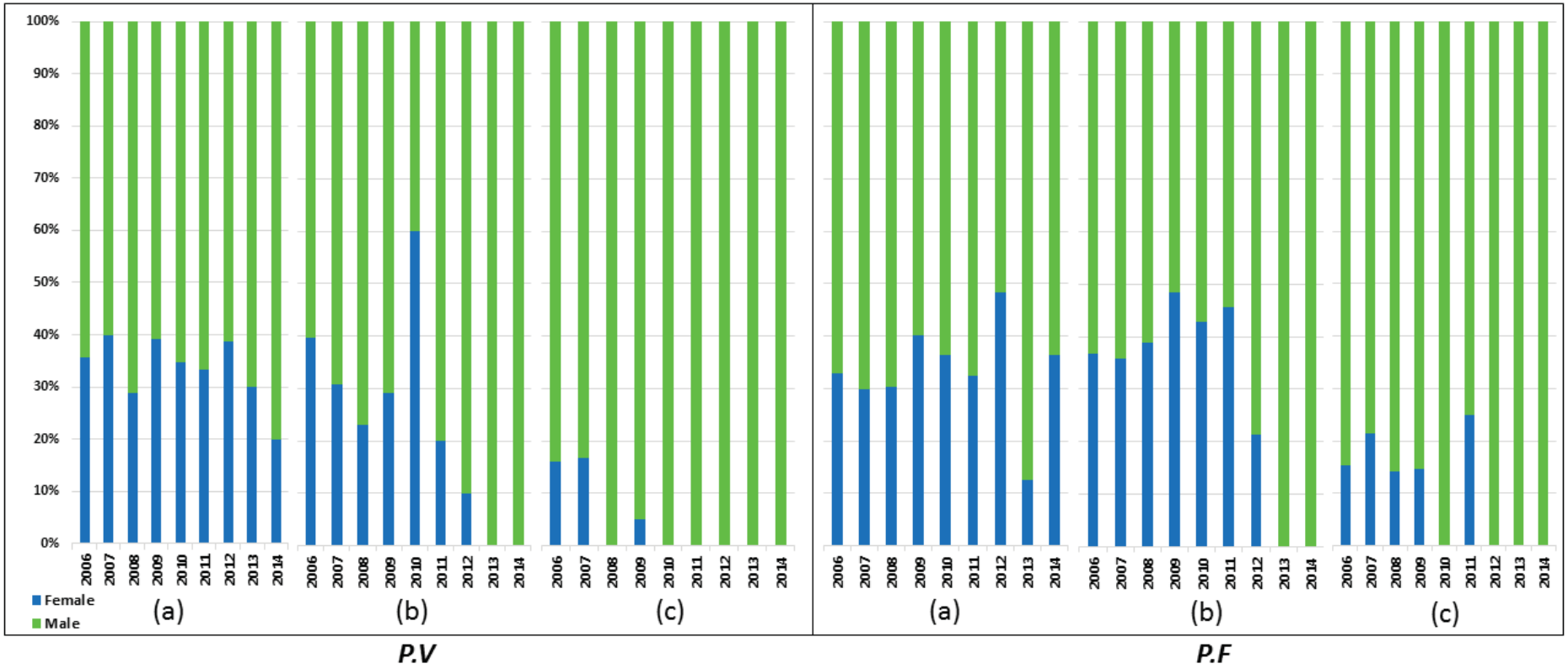
Supplement to: Wangdi K, Banwell C, Gatton ML, Kelly GC, Namgay R, Clements ACA. Malaria burden and costs of intensified control in Bhutan, 2006–14: an observational study and situation analysis. *Lancet Glob Health* 2016; **4:** e336–43.

Appendix

Appendix 1 Proportion of P. vivax (P.V) and P. falciparum (P.F) infection by age group from 2006-2014 amongst: (a) Bhutanese nationals, (b) Foreign nationals residing in Bhutan, and (c) Foreign nationals daily visitors



Appendix 2 Proportion of P. vivax (P.V) and P. falciparum (P.F) infection by gender from 2006-2014 amongst: (a) Bhutanese nationals, (b) Foreign nationals residing in Bhutan, and (c) Foreign nationals daily visitors



Appendix 3 Table showing the cost of different commodities from 2006 to 2014 (USD)

Year	2006	2007	2008	2009	2010	2011	2012	2013	2014
Coartem (%)	68,66·40 (1·4)	1,197·00 (2·3)	1,761·98 (3·1)	2,3073·12 (15·5)	344·74 (0·1)	1,005·7 (1·7)	75·17 (0·1)	55·00 (0·0)	15·34 (0·1)
Microscope (%)	6,776 (1·4)	0 (0·0)	7,218·75 (12·6)	4,592·84 (3·1)	0 (0·0)	2,960·6 (4·9)	7,697·56 (9·3)	0 (0·0)	0 (0·0)
Pump (%)	1,126 (0·2)	0 (0·0)	0 (0·0)	3,666·74 (2·5)	3,596·74 (0·8)	0 (0·0)	4,156·6 (5·0)	4,120·6 (1·6)	0 (0·0)
LLIN (%)	445,453·17 (89·3)	35,804·79 (68·4)	38,923·32 (67.9)	108,361·13 (72·8)	460,808·4 (96·6)	50,605·32 (83·5)	63,596·16 (76·5)	255,821·1 (96·2)	16,327·08 (89·0)
RDT (%)	38,751·8 (7·8)	15,374·97 (29·4)	9,400·47 (16·4)	9,067·12 (6·1)	12,354·24 (2·6)	6,039·48 (10·0)	7,655·97 (9·2)	5,846·02 (2·2)	2,010 (11·0)
Total	**498,973·37**	**52,376·76**	**57,304·52**	**148,760·95**	**477,104·12**	**60,611·10**	**83,181·46**	**265,842·69**	**18,352·42**

Appendix 4 Malaria trend with seasonality