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Technical Report

A School Survey Indicates Conducive Settings for Malaria Elimination in the Highlands Provinces of Papua New Guinea

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Abbreviations

ACT	Artemisinin-based Combination Therapy
BCC	Behavior Change Communication
eNHIS	National Health Information System
GFATM	Global Fund to Fight AIDS, Tuberculosis, and Malaria
HF	Health Facility
LLIN	Long-Lasting Insecticidal Net
MEMTI	Malaria Elimination in Melanesia and Timor Leste
MIS	Malaria Indicator Survey
mRDT	Malaria Rapid Diagnostic Test
NDoH	National Department of Health
NHIS	National Health Information System
NMCP	National Malaria Control Programme
P. falciparum	*Plasmodium falciparum*
P. vivax	*Plasmodium vivax*
PNG	Papua New Guinea
PNGIMR	Papua New Guinea Institute of Medical Research
RAM	Rotarians Against Malaria
SMS	School Malaria Survey
Swiss TPH	Swiss Tropical and Public Health Institute
WHO	World Health Organization

Executive Summary

1. A school survey was carried out between July and November 2019 in the Highlands Region of Papua New Guinea to investigate the local transmission of malaria.
2. The survey was implemented in 30 pairs of primary and elementary schools in the following provinces: Chimbu (n=3), Eastern Highlands (n=5), Enga (n=5), Western Highlands (n=7), Jiwaka (n=2), Southern Highlands (n=4), and Hela (n=4).
3. A cross-sectional survey design was applied for schools selected at the provinces combined with a reactive case detection at the households of a subsample of students.
4. A total of 5,575 students and 1,048 household members from 137 villages were tested using malaria rapid diagnostic tests.
5. Only 13 cases of malaria were detected using mRDTs: nine falciparum, three non-falciparum, and one mixed infection. All positive participants were older than ten years.
6. Malaria prevalence were 0.12% and 1.53%, among the students and household members, respectively.
7. No infection was detected in areas below 1500m, and positive cases were clustered at higher altitudes, all except one at above 2000m.
8. Eleven of the thirteen detected cases (84%) had reported a history of recent travel mainly to lower-altitude endemic areas.
9. Travel in the previous month was reported by 17.5% and 10% of the students and household members; however, endemic coastal areas were the destination for only 4% and 3.8%, respectively.
10. The odds of malaria infection are significantly higher among surveyed participants with a travel history, 9.7-fold in the students, and 123.7-fold in the households.
11. LLINs use by household members is 84% below 1200m, 44% at altitudes 1200-1600m, and remarkably dropped to 14% above 2000m.
12. Over 90% of household members went to sleep by 10 pm but younger household members (i.e., age <16 years) tend to sleep earlier compared to older age groups.
13. Prevalence of anemia were 20.2% among students and 23.3% among household members, but these percentages varied between the provinces. Severe anemia (Hb < 8 g/dl) was only 0.13% and 0.25% among students and household members, respectively.

14. Three of the six RDT-positive students had missed the school during the last two weeks because of sickness. School absenteeism due to sickness was reported by 11.6% of the tested students but only 6.4% had visited a HF and 0.87% were diagnosed with malaria.
15. Positive household members in the RCD survey were neither sick nor sought treatment in a HF. While a recent fever was reported by 3.6% of the household members, only 1.3% had visited a health facility for treatment.
16. The incidence rates 2019 among the whole population and children groups in the near HFs are all below 100 cases per 1000, which correspond with the current prevalence results and show very low transmission intensity in the surveyed areas.
17. We further divided the surveyed areas by altitude into the following strata: 1) low risk at altitudes <1200m, 2) low risk with epidemic potential at 1200-1600m, 3) very low risk dominated by importation at 1600m-2000m, and 4) extremely low risk with only importation at altitudes above 2000m.
18. Our findings indicate conducive settings for malaria elimination in the Highlands of PNG as the prevalence of infection suggests little local transmission but a risk of importation from other areas.
19. There is an opportunity to strengthen surveillance-response systems as an intervention to control imported cases and interrupt malaria transmission in the Highlands region. However, a suitable trigger needs to be identified to justify any further reactive focal intervention.

Introduction

Malaria is endemic throughout Papua New Guinea (PNG) except in the Highlands region, where occasional epidemics occur in certain areas (1-6). While four types of *Plasmodium* circulate across PNG, *P. falciparum* causes most malaria infections in the country, followed by *P. vivax* (7-9). With the vast geography of PNG, varieties of mosquitoes belonging to the *Anopheles punctulatus* group adapt to different ecological niches to maintain malaria transmission (10).

Resting in the heart of the mainland of PNG, the Highlands Region is characterized by the Central Range with deep valleys where agricultural activities are every day. The area is administratively divided into seven provinces, namely: Southern Highlands, Hela, Enga, Western Highlands, Jiwaka, Chimbu, and the Eastern Highlands.

Previous studies in the Highlands showed a negative correlation between malaria prevalence and altitude, especially during non-epidemic periods (1-6). Hence, areas above 2000m are considered non-receptive for malaria transmission, while regions at altitudes 1200-2000m assigned prone-to-epidemics and below 1200m as endemic (11).

In 2015, due to funding cuts, the national malaria control program (NMCP) and Rotarians Against Malaria (RAM) had stopped the distribution of long-lasting insecticidal nets (LLINs) in areas above 2000 meters and targeted only children under five in altitudes above 1600 meters (Tim Freeman, personal communication, 2020). The impacts of this change have yet to be evaluated and if that policy corresponds with the limits of malaria receptivity in the region.

After a significant reduction of malaria burden, which was achieved with Global Fund support in the last decade, a recent upsurge was reported in PNG after about 2014 (12-15). Nevertheless, the increase is not uniform across the country, and malaria risk remains low in the Highlands Region. The Malaria Indicator Survey (MIS) 2016/17 had reported infections in only three villages (out of 20) in the region. Notably, none of the eight malaria cases (out of 1442 tested persons) was in children, suggesting the importation of infections rather than local transmission (12). This very low prevalence of malaria in the region has urged the need for more investigations on locally contracted infections.

One of the malaria surveillance methods that can be useful in low transmission settings is a school malaria survey (SMS) since children are usually less mobile in comparison to adults that can get an infection elsewhere. Recently, SMS has gained increased attention for national surveillance, complementing household surveys. Schools are often well organized, easily accessible, and provide the possibility of collecting malariometric data from many children in a short period, and at a low cost compared to Demographic and Health Surveys (DHS) or MIS (16-18). As a result, school surveys could be useful for understanding local transmission and planning targeted intervention toward elimination (16).

In this work, we conducted an SMS in the Highlands provinces to investigate autochthonous transmission in the region. Hence, the surveys were carried out in thirty "pairs" of elementary and primary schools selected from the seven provinces. Prevalence of malaria in schoolchildren aged 5-16 years and associated travel history information was used as a proxy measure for locally acquired malaria infections.

In addition, we carried out a Reactive Case Detection (RCD) survey at the household level to confirm further whether tested students were indicative of local transmission and if there was clustering of cases in households of positive cases. Previous studies showed that malaria cases cluster in space at the household level, near breeding sites, and affected by human/mosquito behaviors (19-21). Hence, RCD is useful to track down the source of malaria infections. The RCD approach has been used in several studies to find and treat asymptomatic malaria cases living near index ones (22-25).

Objectives of the survey

A school survey was carried out in the Highlands Region to investigate the local transmission of malaria. In a collaboration between the PNG Institute of Medical Research (PNGIMR) and the Swiss Tropical and Public Health Institute (Swiss TPH), the survey was conducted between July-November 2019.

The primary purpose of the SMS was to contribute to an updated stratification of malaria risk in PNG to optimize the implementation of preventive and curative interventions and ensure limited resources are used in an efficient and justified manner. As malarious countries are moving towards elimination across the globe, updates on malaria situations, especially in border areas with natural non-receptive conditions, become essential to better plan and use proper interventions.

Methods

3.1) Selection of schools

A list of 784 primary and 1719 elementary schools received from the national Department of Education (Office of the Research and Data Analysis) as functioning in the seven provinces of the Highlands was used as a sampling frame. This sampling frame was used to generate a list of thirty selected schools and up to two backups. Because SMS aimed to screen malaria in school students 5-16 years, pairs of elementary (grades 1 and 2) and primary schools (grads 3-8) were selected to cover the entire age range. Hence, the closest elementary schools within catchment areas were chosen during the fieldwork. To account for altitude and malaria situation factors, a stratified methodology was used to sample the schools. Three categories of malaria incidence were used in the selection: low (<1), moderate (1-10), and high (>10 per 1000), see **Appendix A**. Hence, catchment areas of schools were delineated using spatial analysis tools. The delineated polygons were categorized by risk factors before a weighted number of schools was randomly sampled using a random number table in STATA.

3.2) Selection of students and households for RCD

Within each school, up to 200 students were randomly sampled from a list of all pupils with a male to female ratio of 1:1. Up to 10 households of students tested positive, and ten households of students tested negative by mRDT were visited for an RCD survey. Households for RCD were randomly sampled from among the tested students in each school. In the selected households, all available household members were tested for malaria (with a target of 1784 household members).

3.3) Data collection forms

The two surveys were implemented using six data collection forms. For the school survey, three data collection forms were used: a school summary form (form S1), a malaria test register (form S2) and, a student questionnaire (form S3). Forms S1 and S2 were completed by the team leader and research nurse, once in each school, while form S3 was an electronic structured questionnaire administered to the selected students. Besides, three electronic questionnaires were used during the RCD survey and were applied to the household head and other household members. These forms were adapted from the Malaria Indicator Survey set of questionnaires (26) and included: 1) a household questionnaire, 2) a treatment-seeking questionnaire, and 3) and a prevalence form. Questionnaires were programmed in Open Data Kit (ODK) at PNGIMR and administered using tablet computers. Paper copies of each questionnaire were available as a backup.

3.4) Survey implementation procedures

The school malaria survey was carried out between July and November 2019 by three trained field teams working simultaneously at different sites. Each field team consisted of at least one or two nursing officers, one scientific officer, and one or two research assistants. All members of the field teams received extensive training covering project background, the survey protocol and methods, the survey instruments, and blood sample collection techniques for nursing officers who collected blood samples.

The survey was conducted in seven highlands provinces of PNG. Before surveying in a particular province, provincial education and health authorities were informed of the scope of the survey, the selected sites, and the planned timing of the survey. A local health officer was requested to accompany the survey team. Upon arrival in a selected school, the team established contact with the headteacher of the school. A meeting with parents and the school board was held to explain the study and methods used. Upon receiving consent from the headteacher, and verbal permission from parents, the random sampling of students was done at the class. RCD interviews were completed with a household head providing written consent, and verbal assent was obtained from household members before collecting a blood sample. The survey took 6-7 days per school (including RCD houses). Handheld GPS devices (Garmin®) was used to record geo-coordinates and elevations of surveyed schools and homes.

3.5) Testing of malaria and anemia

Trained nurses collected blood samples by finger-prick from participants (i.e., selected students and household members) aged six months or older. From the finger prick, one thick and one thin blood smear was prepared on the same glass slide for diagnosis of malaria by light microscopy. Also, an mRDT (CareStart Malaria HRP2/pLDH (Pf/pan) Combo Test, Access Bio) was performed, and a microcuvette sample was prepared to measure Hb levels using a handheld HemoCue Hb 201+ analyzer (HemoCue, Angelholm, Sweden).

Axillary temperature of participants was measured with an electronic thermometer. In addition, children aged (2-9) years were examined for splenomegaly and graded according to Hackett {Hackett, 1944 #525}.

As a community service, mRDTs were also offered to individuals which were not selected but reported having fever in the past two days. The PNGIMR nursing officers provided treatment for mRDT positive individuals following the national treatment protocol, free of charge. Nursing officers also provided treatment for other minor ailments or referral advice to the public in the surveyed villages.

3.6) passive case detection in the near health facilities

Data on malaria cases reported in the near health facilities (HFs) in 2019 was obtained from the electronic Health Information System (eNHIS). The nearest HFs to surveyed schools and households were identified using information collected during the interviews of the SMS and RCD on frequently visited HFs and from the headteachers. Because eNHIS does not report malaria at an aid post level, we confined the analysis only to the nearest health centers and urban clinics. Only confirmed cases by RDTs were used in the analyses. Malaria incidence in the catchment areas of surveyed schools and households was calculated for the whole population, children under five years and at school age (5-14) years. The projected populations and by age groups for 2019 based on Census 2011 (obtained from Department of Statistics) in these areas were used.

3.7) Data management and analysis

Data were collected electronically using the ODK Collect application installed on tablet computers. All data were checked and finalized by the team leader before electronic submission. Completed and verified forms were uploaded directly to the project server at the

Swiss Tropical and Public Health Institute (Swiss TPH) in Switzerland using the local mobile phone network (Digicel). Authorized PNGIMR investigators had unlimited direct access to the uploaded data. ODK Briefcase v1.4.9 was used to download and export datasets for analysis in STATA/IC 14.2 (StataCorp LLC, College Station, TX, USA).

Datasets of schools and households were separately aggregated at provincial and attitudinal levels. Weighted statistics with 95% confidence limits were calculated using the survey design command set in Stata (svy). Schools and households were established as the primary sampling units with the seven provinces as strata. Also, separate sampling weights for schools and household surveys were calculated as the inverse of an observation's probability of selection. To account for the sampling design, the overall probability was calculated as the selection probabilities of the eight constructed categories of altitude and malaria risk among the list of primary schools in the Highlands. The probability of an RCD household being selected within the school was calculated among tested students in each school. Since all individuals of the sampled family were eligible, individual-level weights equaled the weights of the households to which an individual belonged.

Malaria prevalence was calculated as a proportion of individuals with malaria infection detected by mRDT among the tested students and household members. mRDT results were coded as *P. falciparum* (HRP2 test-line only), non-*P- falciparum* (pLDH test-line only), and (potentially) "mixed" infections (HRP2 and pLDH test-lines, whereas this category can also include *P. falciparum*-only infections). WHO adjustments of Hb measurements for sex and altitude (28) were applied prior to defining the anemia status of each tested individual and calculation of prevalence among the study groups. Prevalence proportions of malaria and anemia were also age-standardized using totals of age distribution reported in the Census 2011 by the National Statistics Office (NSO) of PNG.

Using MedCalc software, contingency tables, and odds ratios with 95% confidence intervals were generated separately for the students and household groups to explore the risk of malaria infection by travel history, ownership, and use of bed nets. Where appropriate, Microsoft Excel graphs of percentage and cumulative percentages of frequencies were used to compare the participants' groups. Further, to account for the altitude factor, four categories of altitudes were used in the analyses: <1200m, 800-1200m, 1200-1600m, 1600-2000, and above 2000m.

Bed net ownership and use were calculated following standard procedures (29). The percentage of the population with access to an LLIN was calculated at the household level by creating an intermediate variable named the potential users of LLINS. Hence, the number of LLIN sleeping spaces, assuming two per LLIN, was calculated as potential users and then divided the number of people sleeping in the household the previous night. However, the access proportion was adjusted if the potential use exceeded the number of people in the house the last night, i.e., to converge the access proportion to one. Net use among the people with access to LLINs was calculated by dividing the number of people using an LLIN by the total population with access (multiplied the weighted proportion with access by the total population).

ArcGIS was used to map the surveyed schools and houses. Raster files of the Global 3D Digital Elevation Model TanDEM-X (30) were obtained from the German Aerospace Center (DLR) and corrected using spatial tools in ArcGIS. Four thresholds of contours were combined into one map: <800m, 800-1600m, 1600-2400m, and >2400m. Using the friction raster (31) of the Malaria Atlas Project (MAP), we mapped the accessibility of positive cases to low-lying areas. The Cost Distance tool of ArcGIS was then used to delineate the time contours (one, two, and three hours) for places that positive cases can reach from their houses.

3.8) Ethics considerations

The study was approved by the Institutional Review Board of PNGIMR (IMR IRB No.1808) and the Medical Research Advisory Committee of the National Department of Health (MRAC No. 18.22).

Before the school survey, a meeting was held with the headteacher, and the scope of the study was explained. The headteacher invited parents and school board members for an information session with the research team, and to be informed of the survey, and the confidentiality of the data, the purpose of the finger prick blood samples collected, and consent was sought.

Participation in the survey was voluntary; consent for all primary school students was based on the passive, opt-out method of parental permission. We assumed that the parents who will not attend the information meetings and do not inform the school of their disapproval of the survey approve their children's participation. Written informed consent was sought from the

head of the household and the headteacher of the school in which finger-prick blood samples were collected. Individual verbal permission was obtained from the participants providing finger-prick blood samples.

Results

4.1) Locations of surveyed schools

Thirty pairs of primary schools and their feeder elementary schools (30+30) were selected across the Highlands provinces: five in the Eastern Highlands, three in Chimbu, two in Jiwaka, seven in Western Highlands, five in Enga, four in Southern Highlands, and four in Hela. **Figure 1** shows the distribution of the surveyed schools in the Highlands. While the elevation of surveyed schools ranged from 937-2409m, minimum altitudes within a 5km diameter around the schools were less than 1600m in catchment areas of 18 schools. Also, none of the surveyed schools or villages were below 800m.

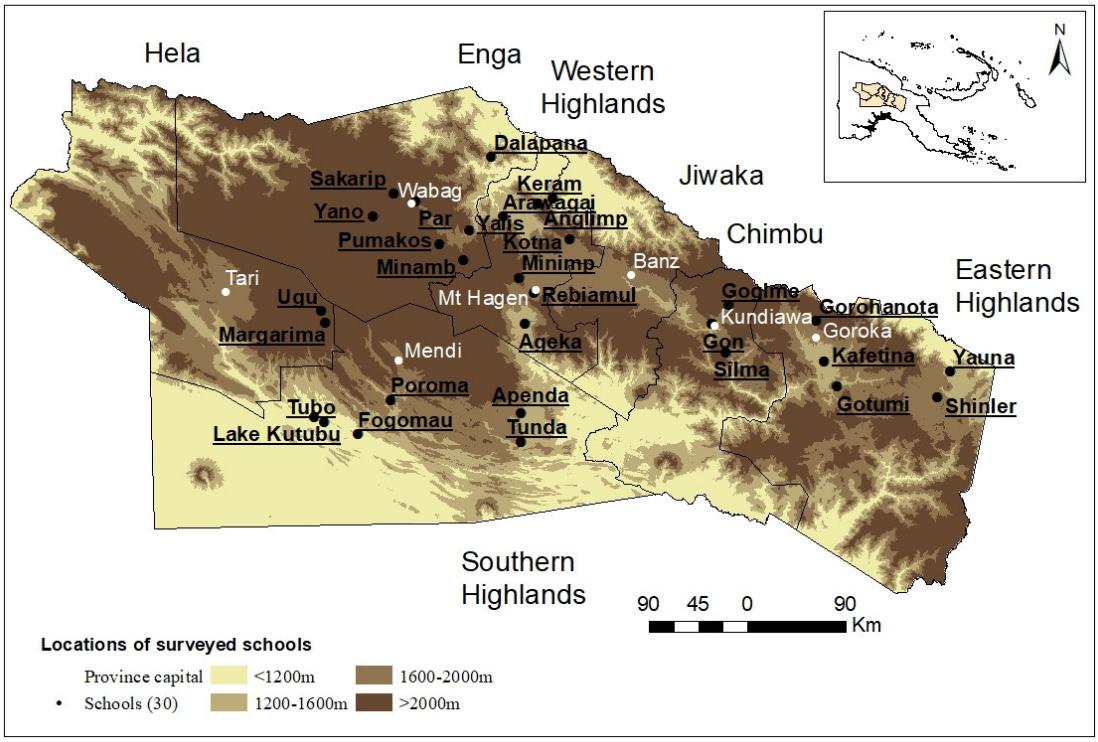

Figure 1. Locations of surveyed schools in the Highlands, PNG 2019. Thirty pairs of primary schools and their nearby feeder elementary schools (30+30) surveyed in the seven provinces. Sites locations are mainly for primary schools.

4.2) Characteristics of SMS and RCD survey samples

Table 1 describes the characteristics of SMS and household RCD survey samples. A total of 5775 students and 1048 household members were enrolled in the two surveys. The RCD participants belonged to 296 households from 137 villages. Children under ten years represented 19.9% and 24.5% of the samples in the SMS and RCD surveys, respectively. Females constituted 49.1% and 52.4% of participants in the SMS and RCD surveys, respectively. Table 1 also lists other characteristics of RCD households, such as the main source of lighting, drinking water, and income. Approximately half of the household heads practice subsistence activities, including farming and fishing. Further information on surveyed students by province and age is provided in **Table B1, Appendix B**.

Table 1. Characteristics of individuals included in the SMS and RCD survey in households in the Highlands provinces (July-November) 2019.

	SMS		**RCD households**		
Province/variable	**School pairs***	**Tested students**	**No. villages**	**No. households**	**No. HH members**
Southern highlands	4	802	11	40	135
Enga	5	906	28	50	123
Western highlands	7	1398	35	70	272
Chimbu	3	560	18	30	196
Eastern highlands	5	1010	26	47	183
Hela	4	698	10	39	62
Jiwaka	2	401	9	20	77
All	30	5775	137	296	1048
Age <11 years (%)		30.5%			25%
Age >=40 years (%)		-			30.5%
Female (%)		49.1%			54.6%
Family size (median)		6			6
Literacy of household head (%)		-			75.9%

Main source of lighting (%)	Solar power	33.9%
	Battery lantern	30.9%
	Electricity	21.3%
Main source of drinking water (%)	Surface	45.6%
	Piped	27.5%
	Water tank	18.2%
Main source of income for the household head:	Farming/fishing	48.4%
	Marketing/ Street selling	17.8%
	Wage job/ public sector	15.8%

* Pairs of 30 primary schools + 30 elementary schools surveyed.

4.3) Malaria prevalence

Table 2 summarizes malaria-testing results of students and household members using mRDTs. Overall, malaria prevalence is very low in the Highlands region, 0.12% (95%CI: 0.05, 0.3) and 1.53% (95%CI: 0.4, 5.7) among the students and the household members, respectively. Malaria infections were detected in only three provinces: Hela (n=6), Enga (n=5), and Western Highlands (n=1). *P. falciparum* is predominant (9/13) among the positive cases, followed by non-falciparum (3/13) and mixed (1/13) infections. Including Pf and mixed results, prevalence of *P. falciparum,* in the SMS and RCD surveys, are 0.07% (95%CI: 0.02, 0.24) and 1.39% (95%CI: 0.3, 5.9), respectively.

For further information on elevations of all schools, number tested, and results among the students and households, see **Table B2, Appendix B**.

Table 2. Malaria RDTs results (positive cases and prevalence) among surveyed schools and households by province.

Province	**No. mRDT cases (Students + household members)**			**Prevalence** (Positive cases/Total tested)**	
	Pf	**Non-Pf**	**Mixed***	**Students**	**Household members**
Southern Highlands	0	0	0	0% (0/802)	0% (0/130)
Enga	2	3	0	0.55% (5/906)	0% (0/123)

Western Highlands	1	0	0	0% (0/1398)	0.37% (1/271)
Chimbu	0	0	0	0% (0/560)	0% (0/194)
Eastern Highlands	0	0	1	0% (0/1010)	0.56% (1/180)
Hela	6	0	0	0.14% (1/698)	8.06% (5/62)
Jiwaka	0	0	0	0% (0/401)	0% (0/77)
All provinces	**9**	**3**	**1**	**0.12% [0.05, 0.3]***	**1.53% [0.4, 5.7]***

*may include *P. falciparum* mono-infections as described in the Methods. **Adjusted prevalence with 95%CI, weighted and age-standardized.

Figure 2 shows malaria negative and positive survey sites in the Highlands. In four schools and ten households, there were mRDT-positive cases among 30 and 296 schools and households, respectively. All positive houses were found in 4 villages and above 1600m, except one residence, which is at 1529m in the Eastern Highlands. In contrast, 132 (46.2%) households without infected household members were located in 59 villages at altitudes below 1600m, among which 30 households belonged to 11 villages at 800-1200m (10.5% of total negatives).

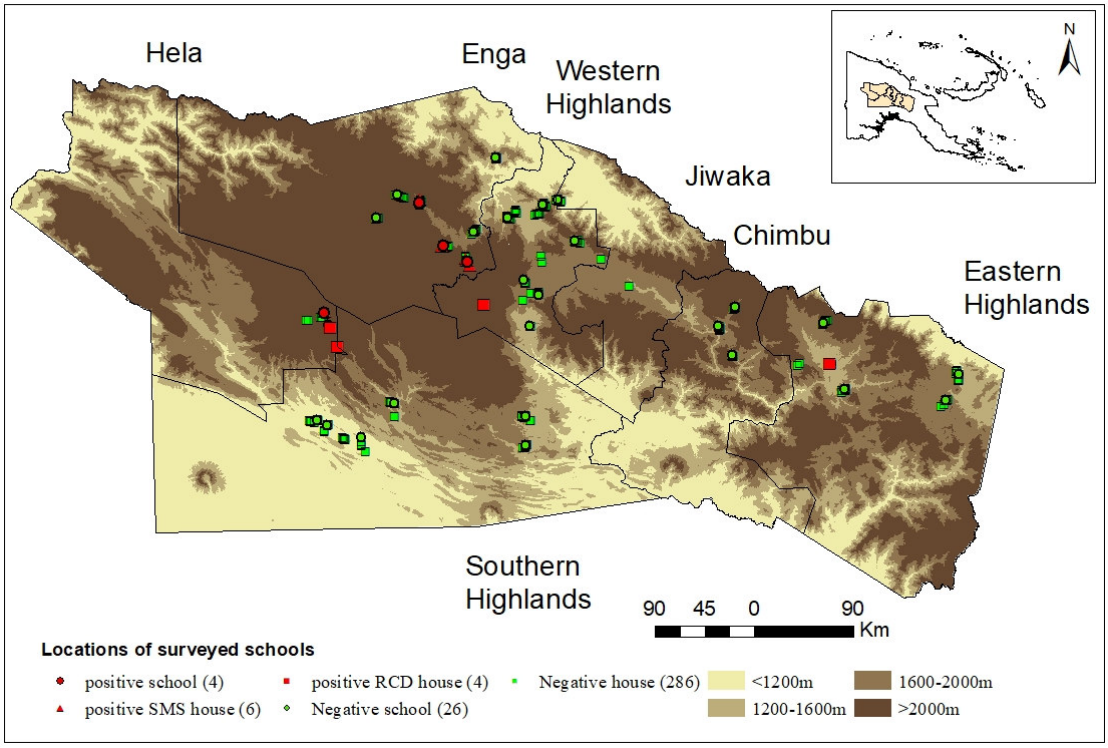

Figure 2. Malaria negative and positive sites in the Highlands, (July-November) 2019. The map shows mRDTs results for positive and negative schools and houses. In some points, symbols top each other because of the map resolution.

Table 3 shows a complete mismatch between mRDTs results in students and their families. None of the positive students had a positive individual in their household. Similarly, the four households with positive members belonged to negative students. Also, the mismatch is noticed at a village scale, i.e., infected students do not relate to villages with positive households.

Table 3. Results of tested students using mRDTs and corresponding RCD households.

Students	**RCD households**			**Total**
	No. negatives	**No. positives**	**Not surveyed**	
No. negatives	287	4	5478	5769
No. positives	5	0	1*	6
Total	292	4	5484	5775

* One positive SMS house in Enga was not surveyed because of the refusal of household members.

4.4) Prevalence of anemia and splenomegaly

All mRDT-positive cases were non-anemic and examined as having normal spleens. The adjusted prevalence of anemia was 20.2% (95%CI: 18, 22.5) and 23.3% (95%CI: 20.2, 26.9) among students and household members. Nevertheless, extent of anemia had varied between the provinces, especially Jiwaka (i.e., most common) and Chimbu (i.e., least common), see **Figure 3**. Severe anemia (Hb < 8 g/dl) was only 0.13% and 0.25% among students and household members, respectively. Out of 1131 students (5-9 years of age) examined for splenomegaly, 2.24% (95%CI: 0.4, 11.7) were found with signs of splenomegaly (Hackett score 1-5). In contrast, none of 227 palpated household members (2-9 years of age) had enlarged spleen. Further analyses on anemia versus missing school days, age, and history of travel are in **Appendix E**.

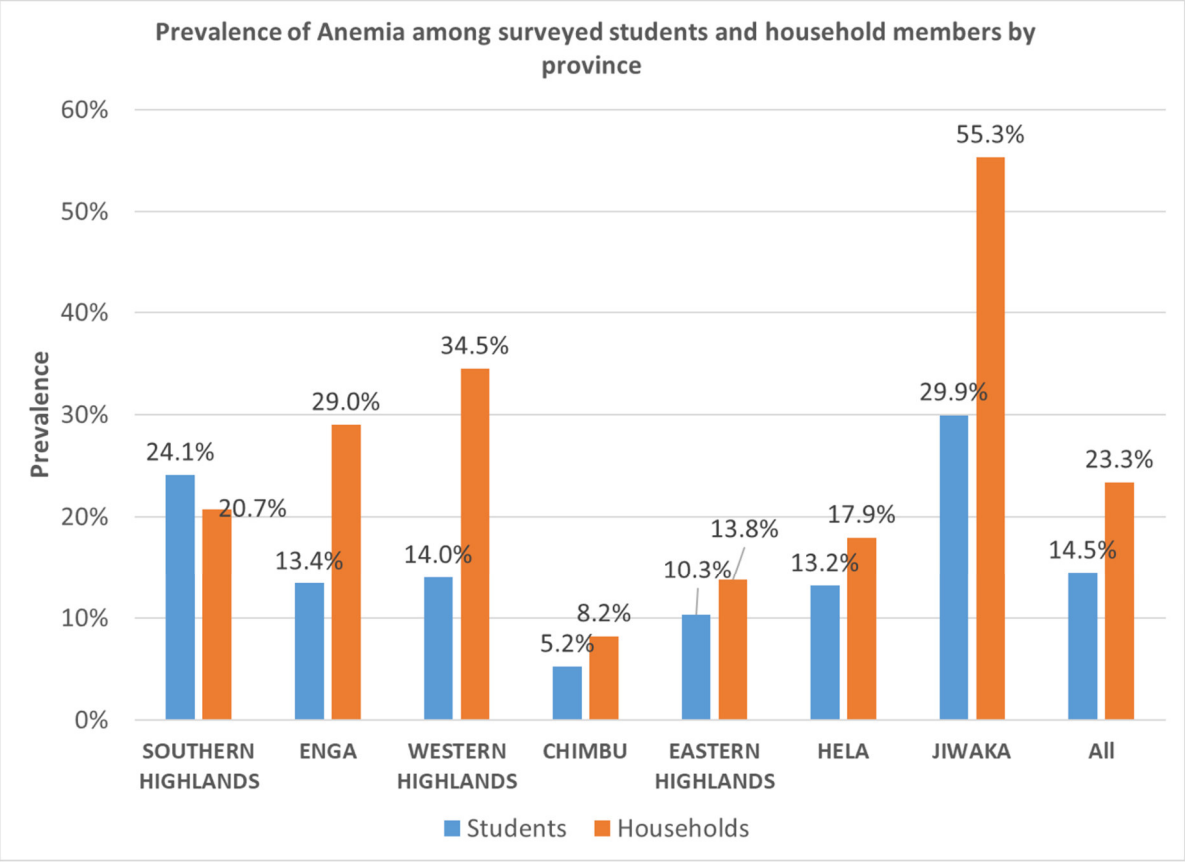

Figure 3: Prevalence of anemia among tested students (N=5774) and household members (N=1037) in the Highlands provinces (July-November 2019). Anemia status is based on hemoglobin thresholds defined by WHO (28).

4.5) Travel history and risk of malaria

Table 4 describes the features of the thirteen positive cases. All malaria cases were asymptomatic, i.e., no fever in the last two days or other common signs (chills, headache, vomiting), except in one case. The age of all positive participants was above ten years, and their places of residence are above 1500m. More important, 11 out of 13 cases (84.6%) reported a travel during the previous month. In particular, a housing cluster of four cases in Margarima station (Hela) reported their travel to three low-lying places. Nevertheless, the two cases with no travel history (Pf and non-Pf) - tested in Enga - live above 2000m.

Table 4. Details of positive malaria cases detected in the SMS and RCD surveys.

No.	DATE	Province	Survey	Residence	Altitude (meters)	Age (years)	Sex	Travel history	RDT result*
1	20/07/2019	EHP	RCD	Ika	1656	11	F	Ramu	Mixed
2	03/10/2019	Enga	SMS	Konimauda	2007	16	M	Lae	Non-pf
3	04/10/2019	WHP	RCD	Kapiapulg	1529	40	F	Madang	Pf
4	16/10/2019	Enga	SMS	Anji	1975	14	M	Hagen	Non-pf
5	16/10/2019	Enga	SMS	Minamb	2168	11	F	POM	Pf
6	16/10/2019	Enga	SMS	Minamb	2034	13	M		Pf
7	05/11/2019	Hela	SMS	Ugu	2337	12	F	Moro	Pf
8	07/11/2019	Hela	RCD†	Margarima sta	2079	40	M	Porgera	Pf‡
9	07/11/2019	Hela	RCD†	Margarima sta	2079	54	M	Madang	Pf
10	07/11/2019	Hela	RCD†	Margarima sta	2079	60	M	Kutubu	Pf
11	07/11/2019	Hela	RCD†	Margarima sta	2079	13	F	Kutubu	Pf
12	07/11/2019	Hela	RCD	Margarima sta	2246	58	F	Madang	Pf
13	08/11/2019	Enga	SMS	Par	1866	10	F		Non-pf

* All positive cases were treated with artemether-lumefantrine in case of Pf result, plus primaquine in case of mixed or non-Pf mRDT result. †Same house in Margarima Station. ‡ Reported fever in the last two days but measured axillary temperature was normal during the survey time.

4.5.1) travel history among the SMS and RCD populations

In Figure 4, travel in the previous month was reported by 17.5% (95%CI: 13.1, 21.8) and 10.1% (95%CI: 07.7, 12.5) of the students and households members, respectively. Among the traveled participants, endemic coastal provinces were the destination of 23% of the students and 40% of the household members. However, travel within the same province or to other Highlands provinces accounted for 67% and 60% of the travel carried out by the students and household members, respectively. For details on the age of students and household members having travel history in the last month, see **Figure C1, Appendix C**.

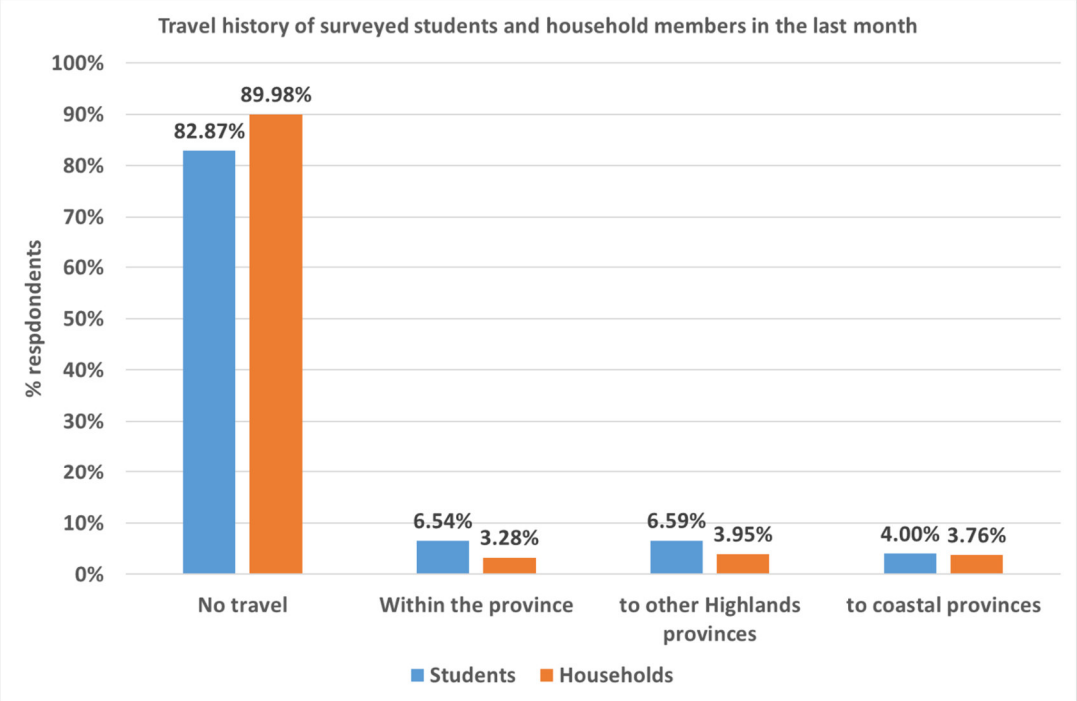

Figure 4. Travel history of surveyed students (N=5772) and household members (N=1037) within the previous month. Coastal provinces include any province in Southern, Momase, or Islands Regions.

The odds of malaria infection are significantly higher among the participants with travel history: 9.7-fold in the students (95%CI 1.77, 53.01, p=0.009), and 123.7-fold in the household members (95%CI 7.02, 2180.61], p=0.001), see **Table 5**.

Table 5. Travel history versus mRDT result (negative/positive) among students and RCD household members.

Travel history*	**No. students†**			**No. household members‡**		
	Negatives (%)	**Positives (%)**	**Total**	**Negatives (%)**	**Positives (%)**	**Total**
No	4780 (82.9)	2 (33.3)	4782	919 (89.2)	0 (0)	919
Yes	986 (17.1)	4 (66.7)	990	111 (10.8)	7 (100)	118
total	5766 (100)	6 (100)	5772	1030 (100)	7 (100)	1037

* Travel history during the previous month (this includes travel within the province, the Highlands region, or other coastal regions).

4.5.2) Accessibility of low-lying areas from households of test-positive cases

In Figure 5, the map depicts a geographical range in which the positive cases can reach within three hours. The altitude in some of the accessible areas is below 1600m. The three contour lines show hourly increments in the time needed to reach any point in the Highlands from their houses (or vice versa). All areas enclosed by the red line are reachable up to three hours from one of the households with a positive case detected in the SMS or RCD. For example, case #1 from Ika village needs only one hour to reach the nearest low-lying area in the village's surroundings. However, the two students with positive mRDT but no travel history - in Par and Minamb, Enga Province - can reach their closest areas at <1600m within three hours. This calculation of accessibility does not take into consideration social and cultural factors influencing accessibility.

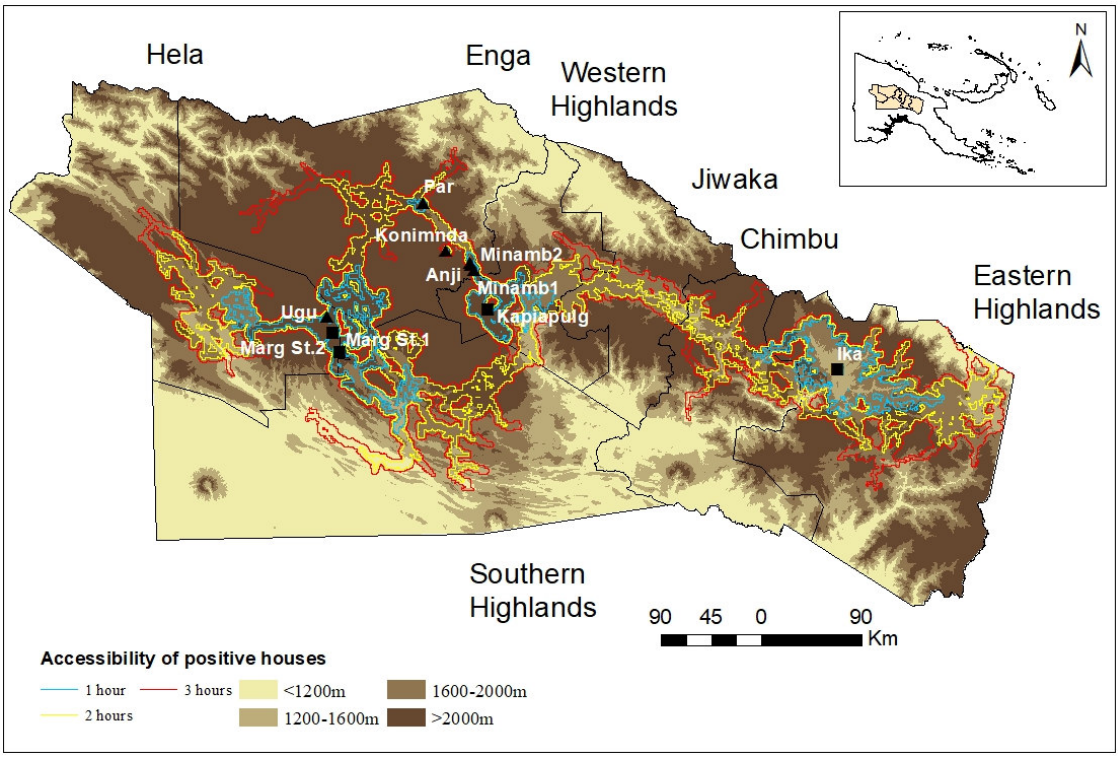

Figure 5. Accessibility of positive cases to areas within three hours. The map shows the geographical extent and altitude that positive cases can reach from their houses using the fastest mode of transportation (calculated using friction data of Malaria Atlas Project).

4.6) Ownership and use of bed nets

Table 6 shows the ownership and use of bed nets by the altitude of RCD households. Apparently, families owning at least one LLIN for every two individuals decreased by altitude from 60.6% in houses at 1200m or below, to 35.04% at 1200-1600m, and 25.6% at altitudes above 2000m. Likewise, the use of LLINs by household members is 84.2% below 1200m, but only 43.6% in 1200-1600m and remarkably dropped to 13.5% in altitude above 2000m. Also, a more significant gap in access to bed nets by individuals is shown for households above 1200m compared to the below elevations, 47.03% and 88.98%, respectively. While LLINs ownership and access by households in 1600-2000m are relatively similar to the proportions in 1200-1600m, there is a 12% drop in bed nets use as the altitude increased.

Table 6. Ownership and use of bed nets in RCD households stratified by altitude (with 95%CI)

Altitude (m)	No. Households (total)*	% of Households ownership [95% CI]			% of Household members [95% CI]	
		Any net	LLIN	LLIN for two§	with access to LLIN†	using LLIN‡
<=1200	30 (241)	100%	100%	60.6% [38.5, 79]	86.98% [77.1, 96.9]	84.2% [68,100]
1200-1600	104 (695)	69.03% [55.8, 79.7]	68.1% [55.2, 78.7]	35.04% [25.6, 45.8]	54.9% [45, 64.7]	43.6% [32.2, 55]
1600-2000	104 (642)	67.3% [55.1, 77.5]	61.7% [49.4,72.8]	33.04% [22.7, 45.4]	55.2% [44.5, 65.9]	31.5% [22.6, 40.4]
>2000	58 (278)	36.1% [20.4, 55.5]	34.4% [18.8, 54.4]	25.6% [11.4, 48]	31.05% [13.2, 48.9]	13.5% [5, 22.1]
All	296 (1856)	62.6% [54.5,70.1]	59.9% [51.9, 67.5]	33.7% [26.5, 41.7]	51.4% [44, 58.8]	34.8% [28.7, 40.8]

* Total in parenthesis is the de facto population slept in houses the previous night.

§Percentage of households with at least one LLIN available for every two people.

†Percentage of household members with access to LLIN within their household. ‡ Percentage of household members who slept under an LLIN the previous night.

4.6.1) Bed net ownership and use and malaria infection

A lack of bed nets is associated with malaria infection in surveyed houses, significantly among the household members (Odds ratio=10.5, 95%CI [1.3, 87.4], p=0.03), but not among the students (Odds ratio=6.3, 95%CI [0.7, 54], p=0.093), see **Table 7.**

Table 7. Ownership of bed nets (any net) in house versus mRDTs results among tested students and household members.

Bed nets in house*	No. students†			No. household members‡		
	Negatives (%)	Positives (%)	Total	Negatives (%)	Positives (%)	Total
No	2551 (44.2)	5 (83.3)	2556	375 (36.4)	6 (85.7)	381
Yes	3215 (55.8)	1 (16.7)	3216	655 (63.6)	1 (14.3)	656
Total	5766 (100)	6 (100)	5772	1030 (100)	7 (100)	1037

Among the respondents having bed nets, two malaria cases (one student +one household member) have reported that they did not sleep under a mosquito net in the last night, **see Table 8**. There was no statistically significant association between net use and positive mRDT ($p>0.05$).

Table 8. Bed nets use versus mRDTs results among SMS students and RCD households.

Sleeping last night under net*	No. students†			No. household members‡		
	Negatives (%)	Positives (%)	Total	Negatives (%)	Positives (%)	Total
No	1033 (32.1)	1 (100)	1034	244 (37.3)	1 (100)	245
Yes	2181 (67.9)	0 (0)	2181	411 (62.8)	0 (0)	411
Total	3214	1	3215	655	1	656

*Only among households reported having any bed nets. † Odds ratio=6.3, 95%CI [0.26, 155.6], p=0.26, not significant). ‡ Odds ratio=5.1, 95%CI [0.21, 124.4], p=0.32, not significant).

4.6.2) Sleeping habits and use of LLINs

Figure 6 shows the cumulative percentage of household members by hours of when they go indoors and go to bed and the proportion that used bed nets (any nets and LLINs). While above 90% of household members reported getting in bed by 10 pm, the overall use of LLINs is less than 40% among the respondents. Also, bedtime of younger household members (i.e., age <16 years) is earlier with a peak at 10 pm compared to older age groups, which is midnight. For the effect of altitude on bedtime and indoor time, please see **Appendix D**.

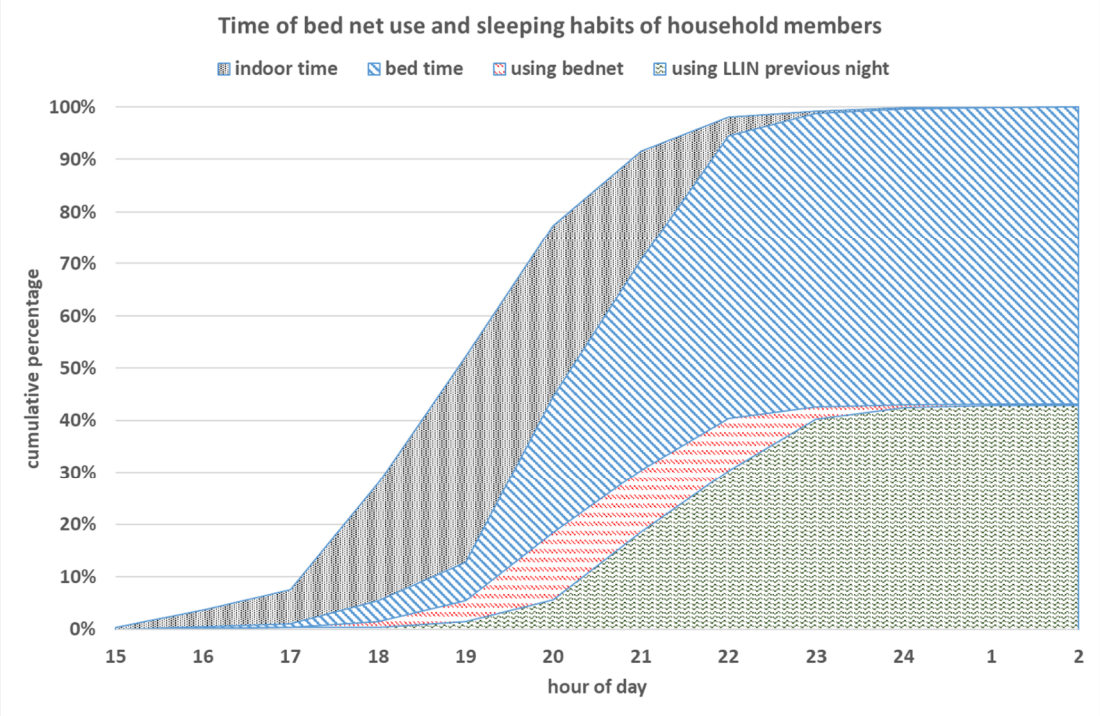

Figure 6. Time of bed net use and sleeping habits of household members. Hourly curves of cumulative percentages were calculated among household members (N=1866).

4.7) Treatment seeking behavior by sick individuals

4.7.1) positive SMS and RCD cases

Among the six positive cases in the SMS, three had reported missing the school during the last two weeks because of sickness. While two of the sick students had visited a HF, no one was diagnosed or treated for malaria. Likewise, positive household members in the RCD survey were neither sick nor sought treatment in a HF.

4.7.2) interviewed students and households

School absenteeism due to sickness during the last two weeks was reported by 11.6% (668/5775) of the interviewed students. Among this group, 10.4% (603/5775) of the respondents reported they had fever but only 6.4% (372/5775) visited a HF and 0.87% were diagnosed with malaria.

While a recent fever was reported by 3.6% (38/1038) of the household members, only 1.25% (13/1038) had visited a HF for treatment. Further details on the treatment-seeking behavior of sick individuals stratified by altitude are shown in **Table 9**.

Table 9. Treatment seeking behavior of sick household members (with fever in the last two weeks), stratified by altitude.

Altitude	**No. without treatment-seeking***	**No. with treatment-seeking at a HF**			**Grand Total**
		Blood not tested	Blood tested		
			Malaria†	No malaria	
<=1600m	7 (46.7%)	6 (40%)	1 (6.7%)	1 (6.7%)	15
1600-2000m	11 (73.3%)	4 (26.7%)	-	-	15
>2000m	7 (87.5%)	1 (12.5%)	-	-	8
Grand Total	25 (65.8%)	11 (28.95%)	1 (2.6%)	1 (2.6%)	38

* Reasons for no treatment-seeking: Do not know what to do (32%); waited to get worse (20%); not bothered/considered not dangerous (16%); no money (8%); others or no reason (20%). †Participants told that they had malaria.

4.8) Transmission risk strata

The total of HFs within the catchment areas of the surveyed areas is 46 including three main hospitals (Kudjip Hospital, Wabag Hospital and Kundiawa Hospital), six urban clinics, 14 health centers and 23 sub-health centers. A list of HFs and incidence rates are in **Annex F**.

Table 10 summarizes malaria incidence 2019 and strata by altitude. Overall, average annual incidence per 1000 in the HFs -- near the surveyed schools and households-- are 6.5, 3.1 and 4.2 cases, among the whole population, children under 5 years and children aged 5-14 years, respectively. Nevertheless, incidence rates varied between the HFs and increased with altitude as the number of HFs (and population) increased. The data obtained from eNHIS did not allow disaggregating the confirmed cases by history of travel.

According to WHO (32), malaria transmission intensity using the annual incidence 2019 (i.e., <100 cases per 1000), suggests a very low transmission in the catchment areas of the schools and households surveyed in the Highlands. We further divided the surveyed areas by altitude into the following strata: 1) low risk at altitudes <1200m, 2) low risk with epidemic potential at 1200-1600m, 3) very low dominated by importation at 1600m-2000m, and 4) extremely low risk with only importation at altitudes above 2000m.

Table 10. Malaria incidence 2019 in near HFs of surveyed schools/households and transmission strata by altitude

Altitude (m)	No. HFs	Cases*	Pop 2019†	Average incidence (per 1000)††			Transmission strata
				All	Under 5years	(5-14) years	
<1200	5	114	67,042	1.81 (0, 5.7)	0.95 (0, 3.1)	1.14 (0, 3)	Low
1200-1600	12	2853	165,751	16.99 (0.4, 118)	6.61 (0, 45)	10.5 (0, 57)	Low (with epidemic risk)
1600-2000	14	938	230,984	3.17 (0, 11)	3.45 (0, 21)	3.69 (0, 21)	Very low (with importation)
>2000	15	485	381,544	2.66 (0, 22.6)	0.53 (0, 2.92)	0.76 (0, 6)	Extremely low (only importation)
All	46	4390	845,321	6.46 (0, 118)	3.05 (0, 45)	4.23 (0, 57)	Very low

* Total cases confirmed by microscopy or RDTs. †estimated population in the catchment areas of HFs 2019. ††Range of incidence rate (min, max) is shown in parenthesis.

Discussion

In this school malaria survey, we investigated a proxy measure for local malaria transmission in the Highlands using students aged 5-16 years since school-aged children are –assumed-- less likely to travel away from their home compared to older age groups. The few positive cases detected in the schoolchildren and RCD households' members correspond well with the incidence rates in 2019 among the whole population and children, suggesting a very low malaria transmission situation in surveyed areas. According to WHO criteria for stratification (32), these prevalence and incidence rates indicate conducive settings for eliminating malaria in the Highlands. The central mountain range -- and associated low temperatures -- reduce the disease risk across the seven provinces. However, intermountain valleys within reach of surveyed communities could increase the risk of malaria to the populations in the Highlands unless appropriate interventions are employed. Previous studies by Mueller and others showed a high prevalence of malaria infections (>20-30%) in the Highlands during epidemic periods and a higher prevalence (1-6). In a school survey in Tanzania, the prevalence was 21.6% among the students. However, the rates had varied with altitudes: 24.6% in areas <750m, 26.7% in 750-1250m, 16.0% in 1250-1750m, but dropped to only 0.2% in altitudes above 1750m (16).

One of the main limitations of this study is under-sampling in some parts of the Highlands, mainly Jimi Valley (Jiwaka and WHP), Karimui (Chimbu), Obura-Wonenara (EHP), Lake Kopiago (SHP), Mt. Bosavi Rural (Hela), and Lagaip/Pogera (Enga). In the latter two zones, ongoing tribal fighting forced the teams to withdraw and replace the selected schools using the backup list. Other areas such as Obura-Wonerra and Lake Kopiago were inaccessible due to flooding during the survey. Hence, we recommend carrying out SMS in these zones; especially, they are likely to be receptive to malaria transmission based on evidence from previous surveys.

An SMS combined with case detection at houses of students could enrich the sample more than conventional prevalence surveys based on selected villages. In this study, the household survey allowed to sample participant from 137 communities lying within the catchment areas of the selected schools. In low transmission settings, prevalence surveys are useful to distinguish local from imported cases, given that children do not frequently travel. However,

children under ten years were only 20% of the survey population at both the schools and houses. A better sampling methodology for prevalence studies in very low transmission settings -- like the Highlands of PNG -- could involve using thresholds of altitude, reported cases in the catchment area, and age to focus on potential transmission hot spots within zones of low transmission. Besides, the history of travel seems to be critical in low-lying areas, especially during agricultural seasons (33).

Among the interventions that can pave the road to eliminating malaria in the Highlands is the use of surveillance as an integral component of the suite of interventions. With few cases detected through the health system and prevalence surveys, the malaria program can respond by focal investigations and the use of malaria commodities to interrupt transmission. However, the surveillance requires a thorough examination of detected cases to determine the source of infection, including travel history and proper monitoring for connectivity routes of potential transmission hotspots with their source of infection. As the epidemiological setting becomes free of malaria, surveillance will be an indispensable tool to prevent a reintroduction(34).

In the present work, all positive houses situate in altitudes above 1500m where air temperature falls below 20°C. At this temperature, the extrinsic incubation period (EIP) for *P. falciparum* and *P. vivax* extends to 30 days and 20 days, respectively (35). Climatic conditions in these sites are suboptimal to allow local transmission of malaria because the EIP could exceed the survival time of adult mosquitoes. Therefore, positive cases detected in the current surveys are unlikely to have been transmitted in catchment areas of their houses. On the other hand, almost half of the negative homes existed at altitudes 800-1600m across the seven Highlands provinces. The population in this unstable setting could be vulnerable to localized outbreaks of malaria. In a previous survey, Mueller and others reported high prevalence proportions(>10%) in 11 villages having epidemics at 1400-1700m in the Highlands(3). A reanalysis of extensive household surveys in 112 communities (2000-2005) had shown a significant difference in prevalence between epidemic and non-epidemic periods, 4.3% vs. 21.2% (median), respectively(1). Accordingly, areas below altitudes 1400-1500m were considered endemic, while regions at 1500-1650 were considered at seasonal risk of epidemics. In contrast, our results show lower prevalence proportions (<1%) in all surveyed schools and villages, even the absence of malaria at supposedly malaria-endemic altitudes

below 1200m. However, the SMS was conducted during the dry season (July and November), i.e., it was less likely for epidemics to occur at altitudes below 1600m. Hence, we recommend a longitudinal survey in the short term to study the interaction of seasonal and altitudinal factors. We used mRTDs instead of microscopy to verify malaria infections in this study. One shortcoming of mRDTs is that it does not allow identifying *P. vivax* infections and results labelled "mixed" could be either *P. falciparum* mono-infections (expressing both antigens) or true mixed infections. Furthermore, mRDTs detect parasite antigens rather than live parasites, which might indicate previous cured infections rather than an ongoing infection. Lastly, mRDTs have been shown to have a low sensitivity for detecting infections in some near-elimination settings in which there is still a sufficient level of immunity in the population to suppress the parasite load to densities below the typical 100 parasites/µl blood detection limit of mRDTs (36).

The two cases of the students without travel history in Enga remain a mystery for our findings. We contacted the house heads again after completion of the survey to recheck any travel during the last year by their children-- especially for the non-Pf case-- but they confirmed no trip in the past. However, the accessibility network of positive cases using MAP friction map and cost distance spatial tools showed the possibility of contracting the infection if there was a day trip to low-lying places in the vicinity of their homes. Tracing routes of movements by positive cases is essential in malaria-free zones to control the source of infection and avoid inappropriate decisions.

The accessibility map showed that the two positive cases with no travel history could theoretically contract the infection if they visit low-lying neighborhoods within three hours of their residences if there was malaria transmission. One of the design limitations of this work is that respondents do not report day trips as travel history, especially if there was no overnight stay in the visited places. The connectivity of local communities across the Highlands with each other is not uniform or depends on topography. Perhaps, this is shaped by social and economic ties between the ethnic groups. Mapping population movements between high and low-risk areas is vital to improving our understanding of malaria transmission in unstable settings. Parasite population genetic studies might aid in such undertakings (37).

The mismatch of malaria cases between the students and their RCD houses implies that the transmission was unlikely to have occurred in the students' homes or their villages. Nevertheless, limitations of this study include the small sample size of tested students and households relative to the low rates of malaria prevalence in the study area and the comparably low sensitivity of the diagnostic approach applied in this first analysis. Hence, while this pilot implementation of RCD provided evidence of the feasibility of a reactive focal search for malaria infections, mRDT-positive students were clearly not suitable index cases to direct control teams to clusters of malaria infections. Whether the symptomatic cases detected passively at health facilities are suitable triggers for reactive focal interventions as implemented, for example, in the low-transmission setting of Zanzibar (38) or in a trial in Namibia (39), remains to be established for the Highlands of PNG.

The travel history reported by positive cases underscores the importance of tracing the source of infection in low malaria settings. The risk of contracting the disease on travel is significant for vulnerable groups lacking immunity like the highlanders. However, few participants had reported a journey within the last month, including coastal provinces Madang and Morobe. What is more, all except one mRDT-positive case was asymptomatic, suggesting either a false-positive mRDT due to a previous cured infection, source of parasite population that is distinct with chronical traits, or partial immunity. The latter would beg the question how immunity is maintained in the absence of local transmission. In contrast, there is a need to study diversity and importance of parasite populations circulating in the Highlands. In Zambia, a difference between asymptomatic and symptomatic cases was attributed to two genetically different populations of *P. falciparum* (40).

As the Highlands become more connected with endemic provinces, the risk of outbreaks associated with the importation of malaria may increase in the absence of any immunity (1). A previous study reported travel to the coasts by 82% of malaria cases in Goroka (33). In unstable transmission settings, imported cases from Madang or Morobe via the Highway could result in devastating epidemics to local communities.

While less than 20% of participants reported travel during the previous month, most of the trips occurred within the Highlands region. Endemic coastal provinces were the destination for 10 to 17% of traveled survey participants. Even a single imported case could result in a malaria outbreak in receptive areas if optimum conditions existed.

Although coverage and effective use of long-lasting insecticidal nets decreased with altitude, the risk of local malaria remains low in the Highlands. Due to recent cuts in Global Fund funding for malaria control in PNG, after 2014, LLINs are not distributed in villages at altitudes > 2000 m, while children < 5 years are the only targeted group in areas of 1600-2000m. In this survey, we revealed gaps in access and use of LLINs -- both above 40% --for household members living at the epidemic-prone altitudes 1200-1600m. In Tanzania, the use of bed nets by students had decreased with elevation: 82.7% in areas <750m, but declined to 59% in 1250-1750m, respectively (16). At the same time, the late sleeping time of older people in the Highlands reduces the effectiveness of LLINs against malaria vectors. Hence, other supplementary interventions, such as mosquito repellents, are needed to protect the vulnerable age groups.

Put into context, our findings of the school survey show an opportunity to eliminate malaria in the Highlands, though sporadic outbreaks may occur in the region. A recent report for the initiative of Malaria Elimination in Melanesia and Timor Leste (MEMTI) recommends developing a road map for elimination in PNG "that considers a phased sub-national approach to elimination, implementing tailored suites of interventions to provinces"(41). Instead of taking the whole country into a stage of a pre-elimination, the WHO framework of elimination calls national control programs in malarious countries to plan and implement interventions in a "continuum of malaria transmission from high to very low"(32). Hence, we suggest using a surveillance response system as an intervention in the Highlands region. Nevertheless, strengthening the National Health Information System (NHIS) including real-time reporting mechanisms of index cases would be the first step towards malaria elimination in PNG.

Conclusion:

The school survey indicates conducive settings for elimination in the Highlands of PNG with the little local transmission but the possible risk of importation of infections. There is an opportunity to strengthen surveillance-response systems as an intervention to control imported cases and interrupt malaria transmission in the region. However, a suitable trigger needs to be identified to justify any further reactive focal intervention.

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Appendices

Appendix A

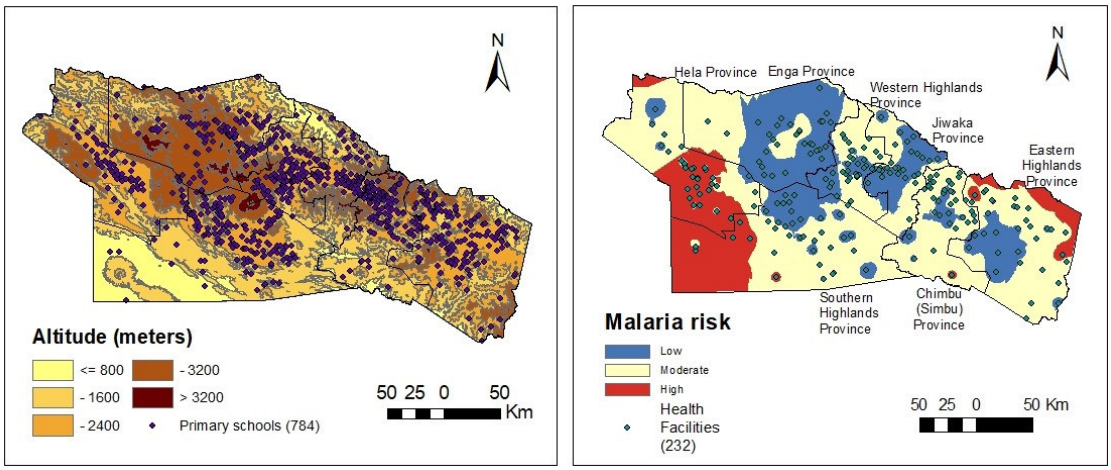

Figure A1. Provinces of the Highlands: a. contours of altitudes and distribution of primary schools; b. malaria risk strata and distribution of health facilities.

Table A2. Distribution of primary schools in the Highlands according to the nine constructed categories and number of schools to sample.

Constructed category (Altitude and Malaria Risk)	**No. primary schools**	**proportion**	**Number of schools to sample**
<=1600 m & Low risk	19	0.02	1
<=1600 m & Moderate risk	68	0.09	3
<=1600 m & High risk	14	0.02	1
1600-2400 m & Low risk	234	0.30	9
1600-2400 m & Moderate risk	327	0.42	11
1600-2400 m & High risk	42	0.05	2
>=3200 m & Low risk	55	0.07	2
>=3200 m & Moderate risk	25	0.03	1
Total	**784**	**1**	**30**

Since there was only one school found in the category: "3200 meters & High risk", this category was removed and combined into the category: "3200 meters & Moderate risk".

Appendix B

Table B1. Number of surveyed students by province and age

	Student Age (%)			
Province	**(5-8) years**	**(9-12) years**	**(13-16) years**	**Total (%)**
SOUTHERN HIGHLANDS	110 (13.7%)	242 (30.2%)	450 (56.1%)	802 (13.9%)
ENGA	88 (9.7%)	344 (38%)	474 (52.3%)	906 (15.7%)
WESTERN HIGHLANDS	225 (16.1%)	553 (39.6%)	620 (44.3%)	1398 (24.2%)
CHIMBU	79 (14%)	251 (44.4%)	230 (41.1%)	560 (9.7%)
EASTERN HIGHLANDS	159 (15.7%)	392 (38.8%)	459 (45.4%)	1010 (17.5%)
HELA	71 (10.2%)	313 (44.8%)	314 (45%)	698 (12.1%)
JIWAKA	43 (10.7%)	192 (47.9%)	166 (41.4%)	401 (6.9%)
Total	775 (13.4%)	2287 (39.6%)	2718 (47%)	5775 (100%)

Table B. Results of tested students and RCD households by school and altitude (m).

Province	**Name of primary School**	**Altitude**	**School students**		**RCD household members**		
			tested	**positive**	**villages**	**tested**	**positive**
SOUTHERN HIGHLANDS	APENDA	1628	201		4	28	
	FOGOMAU	953	200		1	32	
	POROMA	1618	201		2	32	
	TUNDA	1575	200		4	38	
ENGA	MINAMB SDA	2062	178	3 (non-Pf+2Pf)	3	17	
	PAR	1833	171	1(non-Pf)	6	23	
	PUMAKOS	1990	200	1(non-Pf)	7	29	
	SAKARIP	2082	157		7	25	
	YALIS	1512	200		5	29	
WESTERN	AGEKA	1326	196		3	38	
	ARAWAGAI	1517	200		4	34	1 (Pf)

HIGHLANDS	DALAPANA	1420	200		5	34	
	KOTNA	1631	200		4	36	
	MINIMP	2007	200		6	35	
	REBIAMUL	1740	202		9	50	
	YANO	2375	200		4	44	
CHIMBU	GOGLME	1904	200		6	54	
	GON	1636	195		7	90	
	SILMA	1919	165		5	50	
EASTERN HIGHLANDS	GOROHONOTA	1886	200		8	33	
	GOTOMI	1551	209		6	53	
	KAFETINA	1663	201		4	44	1 (mixed)
	SCHINDLER AIYURA	1645	200		4	17	
	YAUNA	1385	200		4	33	
HELA	LAKE KUTUBU	937	199		6	11	
	MARGARIMA	2290	200		1	23	5 (Pf)
	TUBO	974	131		2	18	
	UGU	2409	168	1 (non-Pf)	1	10	
JIWAKA	ANGLIMP	1603	200		4	40	
	KERAM	1545	201		5	37	
Total			**5775***	**6**	**137**	**1037**	**7**

*There is one invalid RDT reported at SILMA PRIMARY SCHOOL (Chimbu), and five students refused to be tested after giving consent in GON PRIMARY school (Chimbu), not included in the analyses.

Appendix C

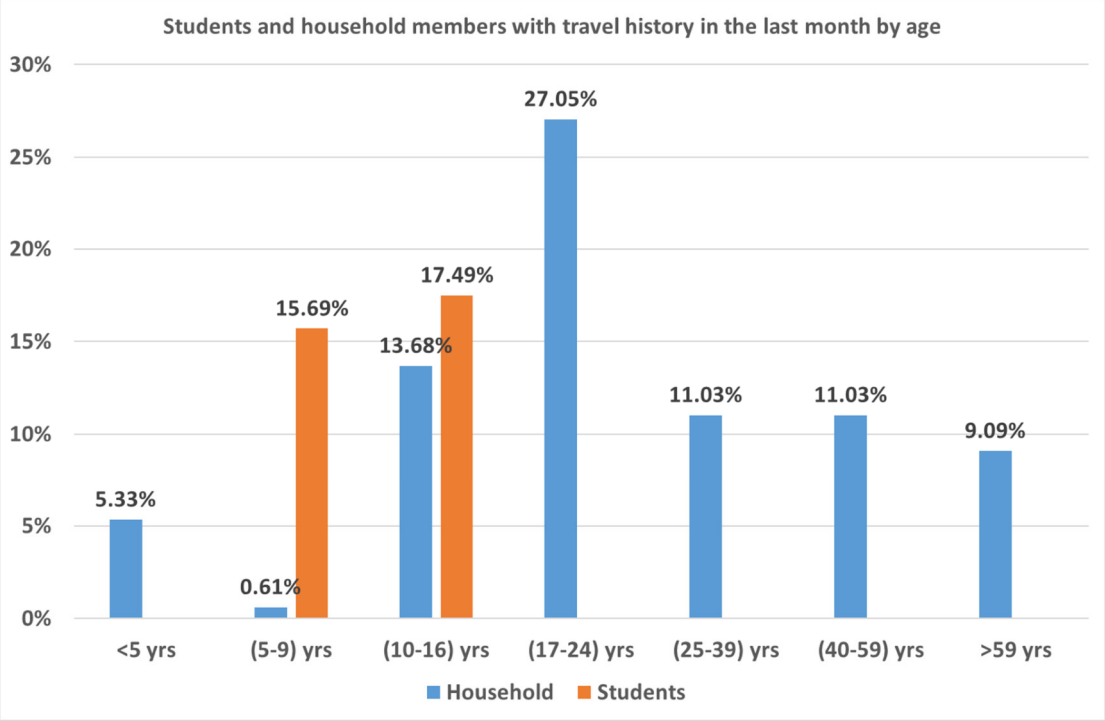

Figure C1. Students and RCD household members traveled in the last month by age.

Appendix D

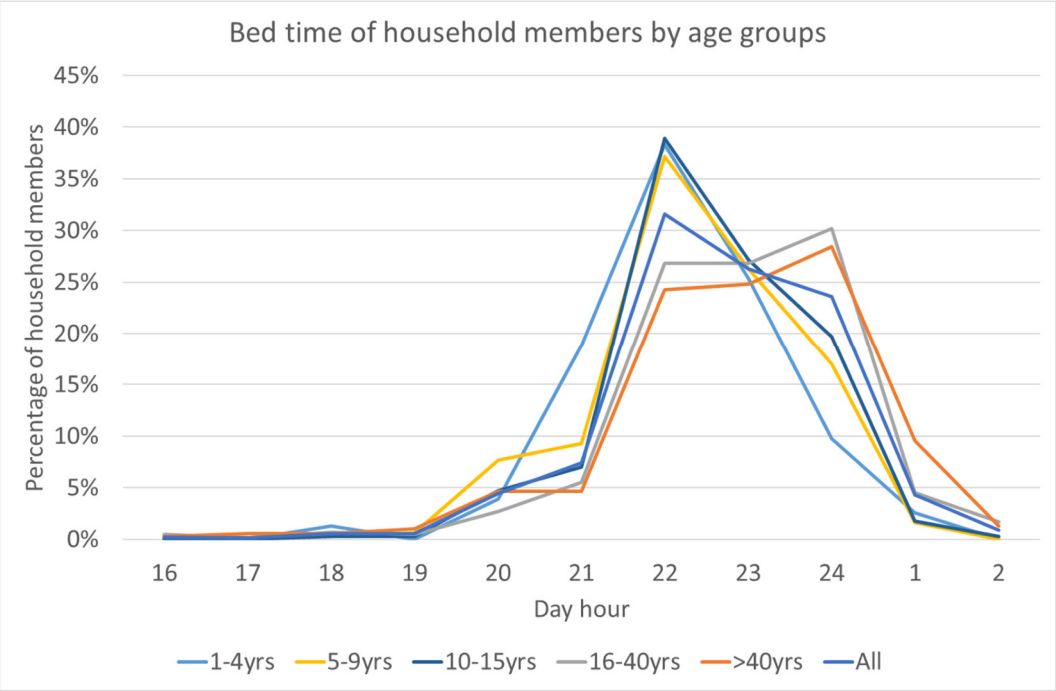

Figure D1. Bedtime of household members by age groups. Percentage of household members sleeping at a specific hour calculated among the age group (N=1866).

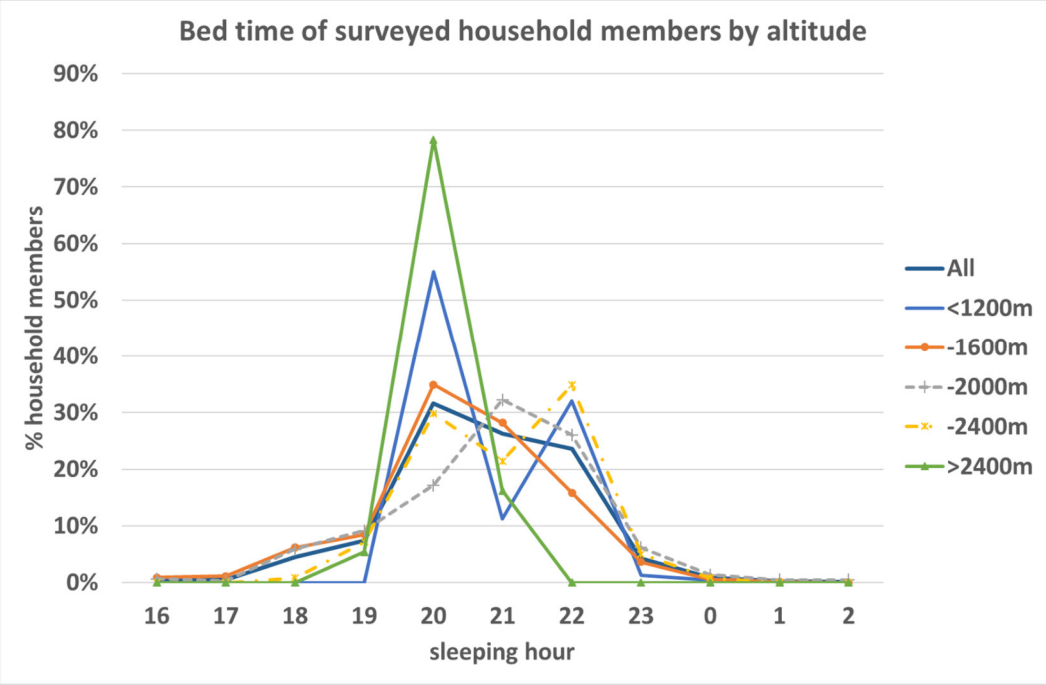

Figure D2. Bedtime of surveyed household members by altitude.

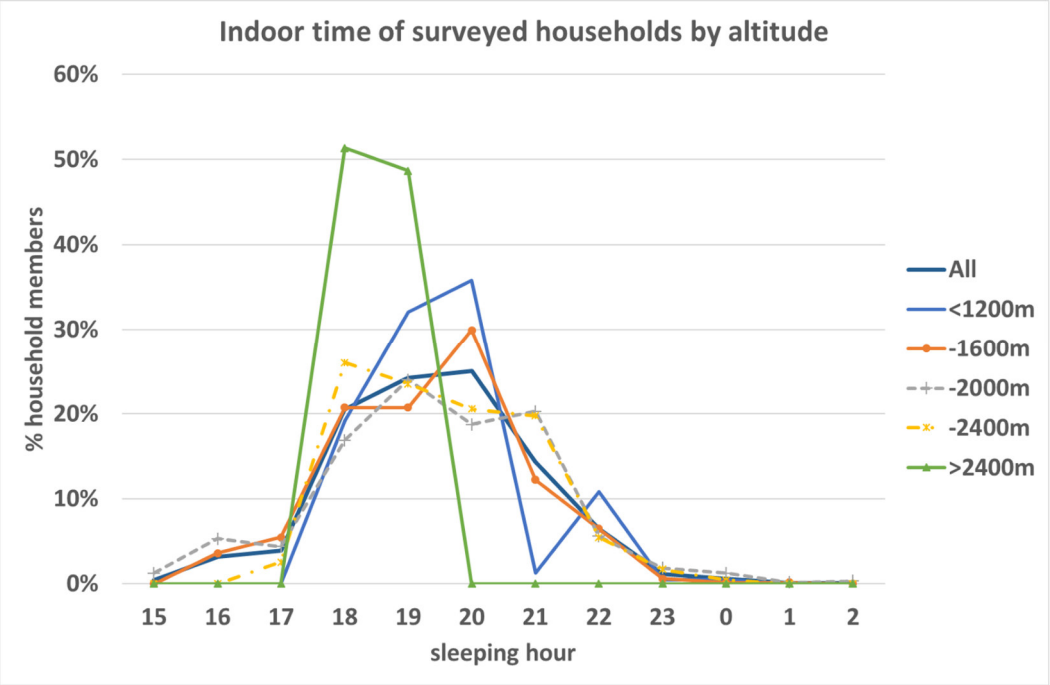

Figure D3. Indoor time of surveyed household members by altitude. People living in high altitudes tend to get indoor earlier than people living in lower elevations do.

Appendix E

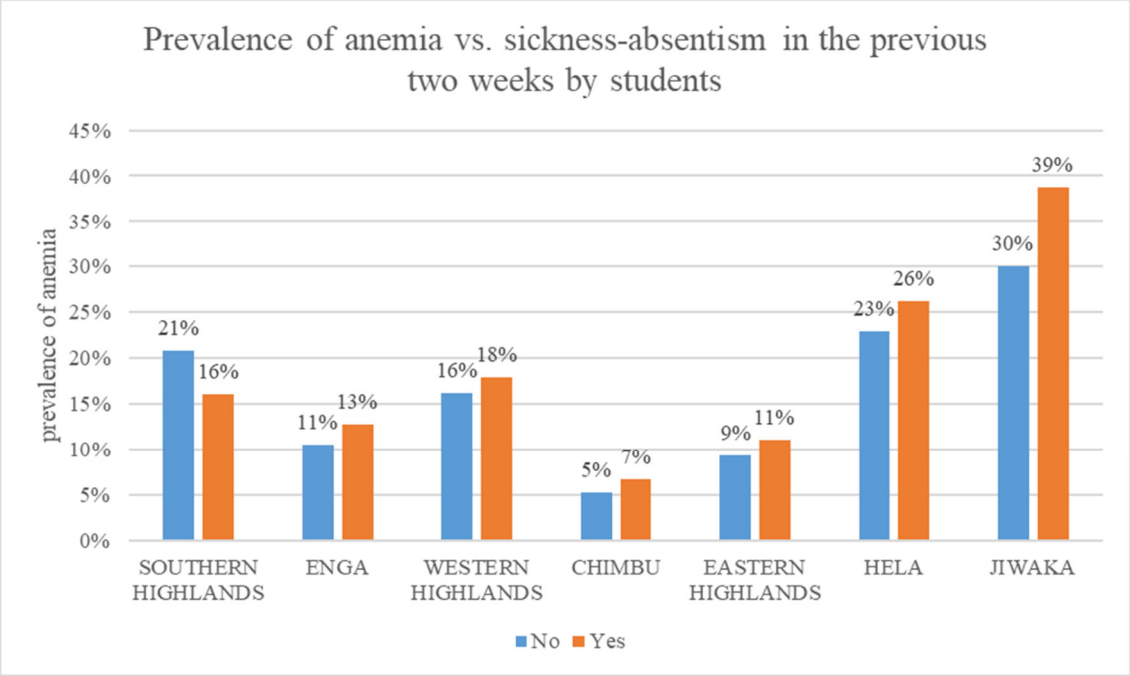

Figure E1: Prevalence of anemia versus school missing by students in the last two weeks.

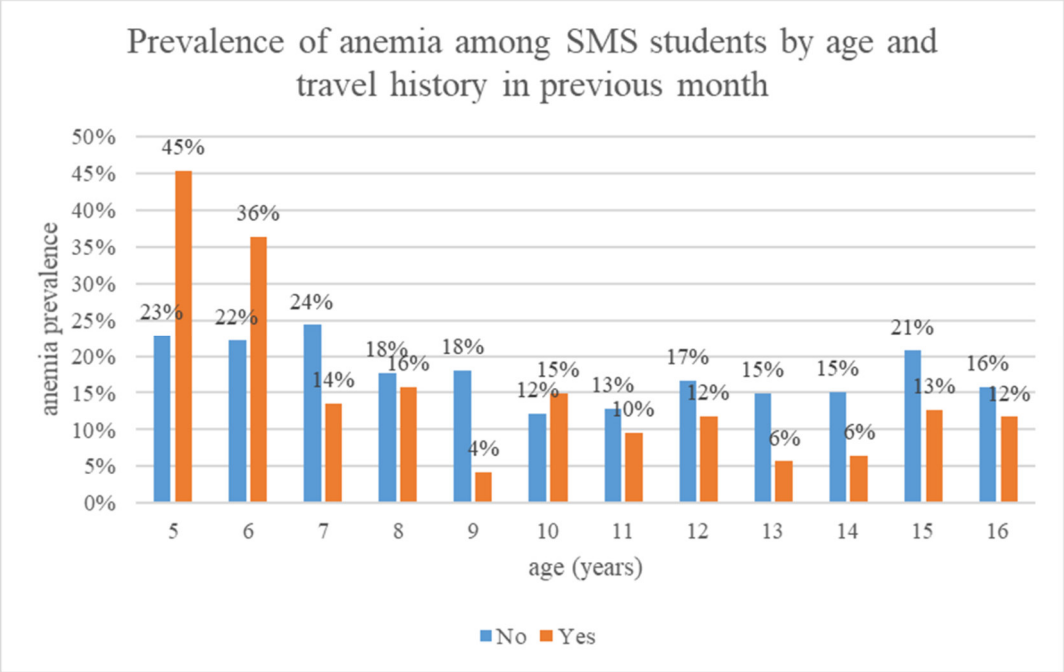

Figure E2: Prevalence of anemia among tested students by age and history of travel in the previous month.

Table **E3**: Prevalence of anemia by province and travel history among the students and households.

Province	Travel history	Anemia prevalence%	
		Students	Households
SOUTHERN HIGHLANDS	No	21.25%	22.05%
	Yes	11.76%	0.00%
ENGA	No	11.99%	26.85%
	Yes	7.48%	20.00%
WESTERN HIGHLANDS	No	16.96%	32.79%
	Yes	11.49%	25%
CHIMBU	No	4.59%	10.79%
	Yes	8.20%	5.13%
EASTERN HIGHLANDS	No	9.52%	14.38%
	Yes	9.84%	19.05%
HELA	No	24.09%	16.36%
	Yes	19.33%	14.29%
JIWAKA	No	32.43%	55.88%
	Yes	20.59%	44.44%
All	No	16.6%	24.46%
	Yes	11.31%	16.95%

Appendix F:

List of Health Facilities (HFs) and incidence rates 2019 in the catchment areas of surveyed schools and households

Province	HF code	HF name	Altitude (m)	Incidence per 1000		
				All population	5-14 years	Under 5 years
Chimbu	100506	Goglme SC	>2000	2.01	0.94	1.43
	100601	Koge HC	>2000	1.57	1.02	0.13
	100501	Kundiawa Hospital	1600-2000	7.28	10.22	14.22
EHP	110202	West Goroka UC	1200-1600	3.9	2.46	0.59
	110302	Henganofi HC	>2000	5.99	1.69	1.83
	110304	Komperi SC	1600-2000	4.92	1.7	0.37
	110203	North Goroka UC	>2000	0.26	0.39	0.45
	110502	Nupuru SC	>2000	0.22	0.1	0
	110608	S.I.L. UC	1600-2000	3.04	5.67	0.97
	110802	Unggai SC	1600-2000	0.39	0	0
	110403	Yauna SC	1200-1600	2.02	1.6	0.81
Enga	80501	Pumakos SC	>2000	1.12	0	0
	80502	Unda SC	>2000	0.35	0	0
	80206	Yampu HC	>2000	22.68	6.27	2.92
	80509	Kungumanda SC	>2000	3.41	0.6	0
	80404	Sopas UC	>2000	0	0	0
	80506	Yalis SC	1600-2000	0	0	0
	80405	Wabag HO	>2000	0	0	0
Hela	70704	Nipa HC	>2000	0.04	0.06	0
	210407	Margarima DH	>2000	0.19	0.27	0
	70702	Inu SC	<1200	0	0	0
Jiwaka	90517	Atenga CHP	1600-2000	2.42	1.37	2.07
	220103	Kudjip Hospital	1600-2000	4.8	4.84	2.98
	90203	Rulna SC	1600-2000	10.71	20.93	21.1
SHP	70719	Aiyo CHP	<1200	1.21	2.96	0.81
	70701	Det HC	1600-2000	2.05	0.63	1.28
	70106	Mele SC	1600-2000	1.88	0.47	0
	70104	Pangia HC	1200-1600	1.44	0	0
	70705	Pimaga HC	<1200	0.89	1.08	0
	70716	Tamenda SC	1200-1600	1.7	0.63	0
WHP	90703	Alkena SC	>2000	1.91	0	1.22
	90518	Kanimareta CHP	1600-2000	0	0	0
	80311	Kepelam SC	>2000	0.17	0	0
	90201	Kotna SC	<1200	5.73	1.69	3.06
	90508	Kumdi SC	1200-1600	3.13	0	0
	220107	Kurki SC	<1200	1.23	0	0.88
	80202	Lapalama SC	1200-1600	7.82	13.63	5.89
	90516	Laprambo CHP	1600-2000	4.11	4.88	5.27

	90311	Newtown UC	1200-1600	0.74	0	0
	90701	Pabarabuk SC	1600-2000	1.2	0.46	0
	90505	Paglum SC	1200-1600	0.4	0.56	0
	90303	Rebiamul UC	1200-1600	117.88	57.31	22.31
	90511	Simbimali SC	1200-1600	23.91	16.37	4.5
	90504	Tinsley HC	1200-1600	40.03	31.33	45.23
	90706	Togoba HC	1600-2000	1.61	0.57	0
	90512	Wakanom CHP	1200-1600	0.86	1.82	0

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