Rapid assessment of correlations between remotely sensed data and malaria prevalence in the Menoreh Hills area of Central Java, Indonesia.

Final report

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Background information

The Menoreh Hills are located to the West of Yogyakarta on Central Java, Indonesia (see Annex 1). Despite the relatively low endemicity of malaria in Java the Menoreh Hills has remained one of several persistent pockets of malaria transmission on the island. The malarious part of Menoreh Hills is shared by two regencies, Purworejo and Kulon Progo, with a total population of about 350,000. The settlements in the hills are mostly scattered and the farmers that live there mainly cultivate rice and practise different types of agro-forestry. The malarious area is covered under eight sub-districts. All sub-districts have health centres with facilities for malaria diagnosis and treatment and for mosquito collection and identification. The health facilities in the area provide a record of all suspected and identified malaria cases and data collected in routine entomological collections. The capacity for sampling, diagnosis and processing of data is, however, not very high and the quality of the records varies within the area.

There are two annual peaks in transmission, one during the dry season in June/July/August and another during the rainy season in November/December/January. It is plausible that these two peaks are caused by different mosquito species, but this has not yet been confirmed. During the past couple of years these peaks have merged, possibly due to meteorological abnormalities. The main malaria vectors in the hills are *Anopheles maculatus* and *An. balabacensis* which both predominantly rest and feed outdoors (exophilic) and prefer to feed on animals rather than humans (zoophilic). Despite these behavioural characteristics they have proven to be efficient vectors of malaria in Menoreh Hills as well as other parts of South East Asia. The main breeding sites of *An. maculatus* are sunlit puddles in stream beds and along the slow running edges of streams. The main breeding sites of *An. balabacensis* are small springs and puddles shaded by canopy, which are abundant during the rainy season.

Intervention methods used at the moment are early diagnosis and treatment and targeted residual house spraying in selected houses in the most malarious desas (groups of villages). Un-impregnated mosquito nets are provided to mothers and their new-born babies in some desas. These efforts have not been able to suppress the seasonal transmission of both *Plasmodium falciparum* and *P. vivax* in a sustainable manner.

The malaria incidence data from the four most endemic parts of the Menoreh Hills are presented in Annex 2, illustrating what appears to be an alarming rate of increase. Furthermore, there have been reports of increased numbers of malaria mortality in the area. The increase in malaria incidence can be attributed to a range of factors coinciding in the area, rather than to one single factor. The factors that are likely to be of greatest importance include:

- Increased parasite resistance to the recommended anti-malarial drugs; Chloroquine and Fansidar (Pyrimethamine/Sulfadoxine).
- Intensified transmission caused by the fact that the anti-malarial drugs administered are ineffective and potentially increase gametocyte rates.
- Decreased national malaria surveillance and control measures since the economic crisis of 1997.
- Return of migrant workers carrying resistant and virulent parasite species/strains.
- Increased transmission risks caused by environmental changes such as deforestation.
The local health authorities now express a justified concern over the situation and there is a real danger that the disease may spread outside the Menoreh hills. The area outside the hills is densely populated and the population is immunologically naive to malaria. The potent malaria vectors *An. sundaicus* and *An. aconitus* occur at high densities. This combination of vulnerability and environmental receptivity provides fertile grounds for major malaria epidemics, if the disease is allowed to spread.

The severity of the situation led to the commissioning of a rapid assessment, which was conducted between July and November 2000. Background information was collected to evaluate options for the development of a research and control strategy for the area. A second objective of the assessment was to evaluate the feasibility of capturing relevant information by remote sensing from an ultra-light aircraft and analysing the remotely-sensed data in a GIS to identify high risk areas and investigate the potential for using environmental management in the local control efforts.

**Materials and methods**

The project employs a variety of methods, including the use of malaria data from the district health centres, entomological collections in selected areas, malaria surveys in a sub-population in selected villages, the use of remote sensing by aerial photography and finally analysis using Geographic Information Systems. The project was conducted and supervised by the Vector and Reservoir Control Research Unit (VRCRU) in Salatiga, Central Java and the Faculties of Medicine and of Geography of Gadjah Mada University in Yogyakarta.

*Selection of villages*

Of a total of eight villages, six were selected among High Case Incidence (HCI) villages with an annual parasite incidence (API) of > 10 cases per 1000 inhabitants between 1996 and 1998. The names of the villages were: Ngemplak, Sekangun, Tegiri, Tangkisan, Kalibuko and Gunungrego. The remaining two villages were chosen among Low Case Incidence (LCI) villages with an API < 5 cases per 1000 inhabitants in 1996-1998. The names of the villages were: Kedung Gubah and SeloTimur. Village positions are presented in Annex 1.

*Parasitological surveys*

Parasitological surveys started July 20th 2000 and were repeated at two-week intervals to a total of six surveys. Blood slides were taken from children between 1 and 9 years of age, to determine malaria prevalence of cases most likely to be indigenous from each village. Blood samples were taken by finger pricking. Two thick blood smears were made for each individual and taken to the nearby health centre. Here the slides were stained with Giemsa and microscopically examined for malaria parasites by reading 100 high power fields. Double checking of the slide readings was subsequently performed at the VRCRU, Salatiga. Children found positive were treated according to the national treatment guidelines. These guidelines at present prescribe treatment with chloroquine plus primaquine in the case of *P. vivax* or a single dose of Sulfadoxine/Pyrimethamine (Fansidar) in the case of *P. falciparum*. 
Entomological surveys
At the same time as the parasitological investigations, entomological surveys were conducted in the same eight villages. Sampling for adult mosquitoes was done using Human Landing Catches (HLC), both indoors and outdoors. HLC were conducted in accordance with WHO standards from 18.00 hrs – 06.00 hrs. In each village, HLC was done by three persons indoors and three outdoors, all supervised by an assistant entomologist. The hourly Man Biting Rate (MBR) was recorded for each event. Morning resting collections were conducted using aspirators inside the houses and in animal shelters often located near the houses. Larval surveys were conducted in the eight villages once a month to identify the most important vector breeding sites. All mosquitoes sampled were brought to a laboratory for species identification using morphological characteristics.

Methodology of the remote sensing and GIS component
The analysis of datasets in a GIS and the interpretation of spatial information was done in stages. The brief description below covers the main steps in the acquisition and analysis of data, database development and spatial modelling using GIS.

Data acquisition
The research required some primary spatial data, including raw and publicly available data, such as: aerial photos, topographic maps, terrestrial and ground-truth data. This information was used for primary database development and a basic environmental analysis, including the interpretation of water and vegetation covers and spatial processing. The data sets specific to this project were derived from aerial photos, topographic survey maps, ground survey data (river, settlements, vegetation, etc) and the parasitological and entomological survey data from the area.

Aerial Photography
Aerial photography consisted of two types, namely Black and White Panchromatic and Small Format Colour Aerial Photographs.
B/W Panchromatic Aerial Photographs in scale of 1:25,000 were acquired from aerial surveys done in October 1992 for the Yogyakarta Special Regency and its vicinity. The database from Panchromatic aerial photograph was developed with the following steps: stereoscopic interpretation, objects classification, then plotted into the base map by free hand digitising. The layers in the database consist of:
(a) **Drainage pattern map** outlining the total stream system in the Menoreh Hills including differentiation of the size of the streams to order 1-5. (the drainage pattern of Menoreh Hills is presented in Annex 3).
(b) **Land use/cover map** classified to (1) City; (2) Settlement; (3) Vegetable Garden; (4) Garden; (5) Mixed garden; (6) Rice field; (7) dry land (Tegalan); (8) Seasonal crop (Tanaman semusim); (9) Grass; (10) Shrub; (11) Bush; (12) Mixed forest; (13) Homogenous forest; (14) Outcrop (Lahan terbuka); (15) Water body.
(c) **Landform map** classified to (1) Alluvial plain; (2) Flood plain (Dataran banjir); (3) Backswamp; (4) Delta-flat; (5) Low level undulating hills; (6) Medium level denudated hills; (7) High level undulating hills; (8) Residual Hill (Bukit Sisa); (9) Pene plain; (10) Foot slope; (11) Damages land; (12) Inter-hill Valley (Lembah antar perbukitan); (13) Anti-clinal hills; (14) Mono clinal hills; (15) Alluvial-marine plain. The land use/cover map is presented in Annex 4.
In addition Small Format Aerial Photographs were made, using a camera mounted on an ultra light aircraft (Trike aircraft) adapted for the special purpose of this research. The results were presented in hardcopy photo prints on scale of 1:5,000. Three series of aerial photos were made in: July, August and September of 2000 of the area containing the eight selected villages. From these Small Format Aerial Photographs, village maps were prepared applying the following steps: conversion of photos to digital format, rasterized by scanning; geometric correction or rectification reference to ground coordinates; photo mozaicking; and on-screen digitising. The resulting maps contain a high level of detail of land use/cover of the area covering the eight villages.

**Topographic Mapping**

The topographic maps used for this GIS were scale 1:50,000 survey maps from Central Java province, numbered 5020 III, 5019 IV and 5019 III. The maps provided the following information: topographic coverage, administrative boundaries and spatial data reference for all thematic maps, such as field surveys and aerial photography.

**Geographical field survey data**

Between November 2000 and February 2001, field-surveys were done for environmental interpretation, verification of ground coordinates and photograph geometric rectification, using a Global Positioning System (GPS).

**Modelling of malaria risk areas**

Based on the knowledge of the ecology of the primary malaria vectors on Java we attempted to develop maps of the areas in and around Menoreh Hills that were prone to malaria transmission. This analysis was primarily done to describe the present risk areas and also where the primary risk areas are likely to be if malaria spreads outside the hill area. The spatial analysis was performed by modelling of spatial data applying four key variables: slope, drainage patterns, land use and expected mosquito flight range.

**Results**

**Parasitological findings**

A total of 194 children were included in the surveys in the six HCI villages and 73 children were included in the two LCI villages. The total combined malaria (P. vivax and P. falciparum) prevalence among the children in the eight villages is presented in Annex 5. The prevalence of P. vivax was highest in the HCI villages with a ratio of 4:1 compared to that of P. falciparum. The ratio of P. vivax to P. falciparum, was 1.5:1 in the LCI villages. Generally there was least malaria in the low areas and most in the high reaches if the hills. When correlating approximate village altitude and the total prevalence of malaria (Fig 1) there seemed to be a trend towards an increase particularly in the villages above 200 meters altitude.
Figure 1. The approximate altitude of the villages and the total malaria prevalence in the villages.

**Entomological findings**

Five different *Anopheles* species were identified in the study villages: *An. vagus*, *An. maculatus*, *An. balabacensis*, *An. barbirostris* and *An. aconitus*, as presented in Annex 6. The total man biting rate for all species is presented in Annex 7. Among the anophelines caught, *An. maculatus* and *An. balabacensis* were the most likely malaria vectors supported only secondarily by *An. aconitus* in certain villages. No clear picture emerged, however, of an association between species composition and malaria prevalence in the children from the same villages. The only figure that stood out from the rest of the data-set was that Kedunggubah had the highest man biting rate and the highest proportion of *An. maculatus* of all the villages, as well the highest total malaria prevalence. On further analysis of the findings for *An. maculatus*, we found that only 18% of the mosquitoes caught by human landing catches had been caught indoors and 82% outdoors. When the resting catches were included in the analysis, 69% of all adult *An. maculatus* were caught in resting catches and only 6% in HLC indoors and 25% in HLC outdoors. For *An. balabacensis* HLC no specimens were caught indoors but only outdoors and when the resting catches were included, 66% of adult mosquitoes were caught resting and 33% by HLC. The larval survey confirmed that *An. maculatus* was breeding in the remaining pools of water in the stream beds and in slow running streams primarily of 2nd, 3rd and 4th order. Surprisingly, we also found an overlap of *An. balabacensis* in the same breeding sites suggesting that the two species to some extend share breeding habitat.

**Mapping the susceptibility to malaria**

The relative risk of malaria transmission or susceptibility to transmission was mapped in several different ways. The models all reflect relative differences in transmission
risk and not absolute levels of transmission. The relative difference is reflected in three risk levels represented by the following colour codes: Red: high susceptibility, Yellow: moderate susceptibility, Green: low susceptibility.

Primarily there was a need to map the relative transmission risk in the individual villages that were surveyed. This was done by identifying the main mosquito breeding areas and add distribution boundaries for mosquito flight range around these breeding areas. An example of such a risk map of one village is presented in Annex 8, showing the buffer zones around the stream systems. Second level of analysis was a coverage developed to show the main risk areas in and around the Menoreh hills based on the assessment that particularly the villages above 200 meters had the highest risk of transmission. The resulting risk map is presented in Annex 9. This was again developed further to narrow down the risk areas within the hill region to the boundary areas around the 2,3,4 order streams where *An. maculatus* and most likely also *An. balabacensis* are breeding. The result is presented in Annex 10. Finally a risk map was developed to illustrate the enormous area in and around Menoreh hills that is under a primary threat should malaria spread outside the hills. In addition to the main transmission by *An. maculatus* and *An. balabacensis*, it was assumed that *An. aconitus* in the flat low lands and *An. sundaicus* in the brackish coastal habitats are significant malaria vectors. The resulting potential future risk map is presented in Annex 11.

Below are described the main parameters for the different levels of risk analysis in and around the Menoreh hills.

A: Main risk areas within the individual study villages (Annex 8).
Coverage's only include the areas around the eight study villages covered by the aerial photography.
Areas <150 meters from 2,3,4 order streams: High susceptibility.
Areas 150 – 300 meters from 2,3,4 order streams: Moderate susceptibility.
Areas >300 meters: Low susceptibility.

B: Risk area according to altitude only (Annex 9).
All risk areas above 200 meters altitude and below 1000 m: High susceptibility.
Below 200 meters: Low susceptibility.

C: Highest risk area within the hill region (Annex 10).
Only areas above 200 meters are susceptible.
Areas <150 meters from 2,3,4 order streams: High susceptibility.
Areas 150 – 300 meters from 2,3,4 order streams: Moderate susceptibility.
Areas >300 meters: Low susceptibility.

D: General risk coverage of the whole area including low lands (Annex 11).
Flat (< 15 %): High susceptibility.
Undulating (15 – 25 %): Moderate susceptibility.
Hilly/mountainous (> 25% ) and no streams: Low susceptibility.
Areas <150 meters from 2,3,4 order streams: High susceptibility
Areas 150 – 300 meters from 2,3,4 order streams: Moderate susceptibility
Areas >300 meters: Low susceptibility

According our analysis of the final risk areas, high risk areas (red) cover 5228 hectares, moderately susceptible (yellow) 2352 hectares, and areas of low susceptibility (green) 2643 hectares.
Discussion

The main motive for initiating this assessment study in 2000 was the rapid increase of malaria cases observed in the Menoreh Hills area over the previous five years. This trend has continued since and more worrying: at the time of writing this report (February 2002) malaria transmission is spreading to parts of Java where the disease has not been seen for decades or even longer. This alarming development needs to be assessed from a number of different perspectives, to better understand local epidemiology and transmission dynamics and to appraise the potential, feasibility and cost-effectiveness of different intervention methods. If no action is taken to stop the current trend, Java is likely to face major malaria epidemics in the next two to five years. The general trend in the emerging epidemic areas seems to be that they occur in foot hill areas with forest coverage comparable to the ecological situation in Menoreh Hills. To shed more light on the driving forces behind this alarming trend and what can be done to prevent the situation from further deteriorating, Menoreh Hills could be used as a benchmark site for understanding the transmission dynamics and identifying appropriate intervention methods.

In the assessment presented here, we attempted to document parasite prevalence rates in community groups in the Menoreh Hills area and to identify underlying factors that could explain observed differences. As an innovative step, we attempted to use remote sensing (RS), by aerial photography of the study areas, and GIS to shed further light on local malaria transmission risks. Admittedly, this was a rapid assessment with a limited scope, focused on finding general phenomena and trends in disease and vector distribution patterns, and not a thorough scientific investigation of the detailed malaria transmission dynamics of the Menoreh Hills area.

The assessment results suggest a correlation between altitude and total malaria prevalence in children from selected villages. A first and simple explanation for this observation would be that as altitude increases, ecological conditions for the key vectors improve. This is supported by the finding of relatively high densities of *An. maculatus* in the highest situated village. It is, however, also possible that this correlation has its origin in the equally significant decrease of access to the diagnostic services and prompt treatment facilities provided by local health centres, most of which are situated in the lower reaches of the hills. Increased prevalence at higher altitudes could thus be a function of long travel distance to the health centres. In all likelihood, the phenomenon is due to a combination of these determinants, but we are inclined to think that the biological explanation prevails. This obviously needs further research in a study that includes more robust parasitological surveys of entire populations and detailed entomological investigations at different altitudes over an extended period of time. In addition, the local treatment-seeking behaviour must be studied to support the development of the best possible delivery systems.

Our findings also suggest that most transmission takes place outdoors, as the vast majority of mosquitoes collected were from human baits outdoors. Direct interpretation of these data and their extrapolation suggest that 80% of all malaria transmission in the Menoreh Hills area takes place outdoors. Control efforts such as residual spraying and the use of impregnated mosquito nets may, therefore, be of limited use. Individual use of repellents, diversion of mosquitoes along the principles
of zooprophylaxis and/or instigating human behavioural change would seem suitable alternatives. It must be stressed, however, that the sampling method using a human bait sitting outdoors may introduce, through its artificial nature, a serious bias, exaggerating the relative importance of outdoor catches. The presumed exophilia of the two main vectors requires further investigations using more neutral sampling methods, before final recommendations regarding control strategies can be formulated. Nevertheless, it remains undeniable that the impact of traditional tools such as residual spraying on vectors that show a substantial level of exophilia will be significantly below their real potential, seriously effecting the cost-effectiveness of this approach.

Our findings further suggest that animal shelters rather than human dwellings provide the most attractive resting place for An. maculatus and An. balabacensis, illustrating their zoophilic tendencies. This characteristic could be used in follow-up research testing the potential of zooprophylaxis for transmission risk reduction in Menoreh communities.

The results of larval collections confirm that during the dry season the preferred breeding places of the key vector species are the small streambeds and streams in the hills. Aerial photography allowed mapping of these streambeds and facilitated the production of risk maps distinguishing areas of different risk levels in the Menoreh Hills area. By combining remotely-sensed datasets with ground-truthed datasets in the GIS we were able to develop several different transmission risk maps for the entire Menoreh Hills area, showing a range of scales in risk analysis. The first level of analysis shows the potential risks within the selected, individual villages. This map was extrapolated to cover the whole of the Menoreh Hills area, showing the size of the risk areas and identifying the villages exposed to the highest risk levels. As a result it is shown, for example, that in Kolun-progo a dangerous combination of high population density and high transmission risk exists. This is, in fact, one of the worst affected areas in Menoreh Hills reporting a high malaria related mortality rate over the past couple of years. It is alarming that other densely-populated settlements are located within areas with a similar potential risk levels, not in the least those in Magelang district. These findings suggest that a deterioration of the malaria situation in the northern reaches of Menoreh Hills may be imminent. The map in annex 11 further illustrates this alarming situation by highlighting the risk areas inside and outside of the Menoreh Hills area. It represents a worst case scenario in case the lowland vectors An. aconitus and An. sundaicus are left unchallenged, sound diagnosis and treatment policies and practices are not put into place and malaria is left to spread freely into the area. Without the deployment of preventive action, this could become the future malaria distribution map of Purworejo district and Menoreh Hills.

It was not the objective of this assessment study to identify and characterize all potential causes underlying the increase of malaria in Menoreh Hills. The assessment results do, however, provide some initial indications of criteria to be used in the development of a sustainable solution for the malaria problem in the area. We know from the history of malaria control that magic bullet solutions are not a sustainable answer. The development of an integrated vector and disease management strategy should build on a solid evidence base, applying reliable epidemiological, ecological and economic criteria. For the deployment of different combinations of interventions, there should be transparent decision-making procedures, allowing adaptation to new
situations over time. It is crucially important to involve local communities in the development and implementation of such a strategy, both from a sustainability and an economic perspective. A first priority would be a further strengthening of our knowledge base and the testing of alternative interventions in the local setting. Some of the suggested methods are of a low-tech nature, such as zooprophylaxis, the use of insecticide impregnated mosquito nets and the application of biological control agents. Others may, by their nature, require the involvement of other public sectors, such as the installation of small infrastructural works in support of environmental management in the riverine systems. Persistent monitoring by the health services will be necessary as well as co-ordination of non-conventional and conventional control activities. The main recommendations for focused control efforts and further research to be carried out in Menoreh Hills are presented below.

Main suggestions regarding control efforts in Menoreh hills:

*Increase of intervention in high risk areas*

The risk maps produced by this study highlight the need to focus interventions in the remote areas high in the hills. These areas are the least accessible, reason for which they are easily overlooked or never reached. On the basis of the current insight, intervention efforts should therefore focus on the villages above 200 meters and include the villages up to the highest reaches of the hills even if present clinical malaria data are lacking or incomplete. Furthermore, transmission risk reduction measures could be targeted at households located within 300 meters from the 1,2,3,4 order streams as these are most likely to be exposed to the highest transmission risks. This could potentially act as a barrier to transmission for the households outside these areas. Since the risk areas are evenly spread over the hills, this highlights the importance of developing a common control strategy across the provincial borders. If one province does not adopt strict control measures, it will continue to serve as a pocket of malaria from where malaria free areas may be re-infested.

*Change of drug policy:*

Based on the existing knowledge there is an urgent need to review and update the anti-malaria drug policy for Java. Further studies should be undertaken but the present level of resistance seems to justify immediate changes in the first and second line treatment strategy. Introduction of combination drug therapy could be an affordable and quick solution. A recent study done by NAMRU-2 in Menoreh Hills suggests that combination of Chloroquine and Fansidar provides high cure rates and could be considered a good choice before third generation, more expensive drugs like Mefloquine, Co-artemether, Malarone etc. become available in Indonesia. This option seems to be the fastest and most affordable way to immediately reduce malaria mortality in the Menoreh hills and it is therefore strongly recommended. Safety and efficacy of this combination therapy is well documented and it has been used, as recommended by WHO, for many years in areas where it is proven to be effective. To make this approach more efficient there is an urgent need to reinforce the diagnostic facilities in the hills, particularly in the most remote areas high in the hills. A GIS analysis of the coverage’s of the existing health centres would as well highlight the areas most in need of additional support and would guide the development of additional health centres or posts in the areas.
Use of impregnated mosquito nets

Even if a large part of the transmission takes place outside the houses some transmission will take place indoors. Very importantly, this transmission poses a risk to that part of the population that remain indoors for longer periods of the night, mainly children. That is why protective measures also must be adopted to interrupt indoor transmission. The use of residual house spraying is the traditional option but it is expensive and can only be organised by the local or central health authorities. An option that is more easy to administer both through the existing health system and the local community, is that of impregnated mosquito nets. Impregnating mosquito nets is in reality a highly targeted use of insecticide and has the advantage that the net can be brought along to other locations like when villagers are temporarily moving to small farm shelters to protect their crops. One of the problems with the impregnated nets is that they must be re-impregnated once every 3-6 months depending on the type of insecticide. A new type of impregnation has, however, been developed where the impregnation lasts for years (virtually the life span of a net) in spite of frequent washing. The product referred to is PermaNets that has a specially developed, durable impregnation. It is therefore strongly suggested that this type of nets are tested both experimentally, to monitor the effect on the mosquito behaviour and survival, and also as a village scale intervention in some of the most endemic villages in the hills.

Main suggestions for future studies in Menoreh Hills:

Description of the general transmission dynamics of malaria in Menoreh Hills.

There continue to be many gaps in our knowledge of malaria transmission in the hills. The evidence base is therefore not yet sufficiently solid to make effective decisions regarding alternative intervention strategies. One of the limitations of the present assessment is that it was only done during the dry season, so data are lacking that would demonstrate seasonal changes in transmission. To validate and refine the malaria transmission risk map of Menoreh Hills, a detailed investigation is needed of the spatial and temporal transmission dynamics in the area. Ideally 16-36 villages should be randomly selected and stratified according to elevation and position in Menoreh Hills. In these villages indoor and outdoor catches should be performed every second week over a full year to get a detailed understanding of the geographical and temporal variation in transmission intensity. The larval ecology should be monitored over the two main seasons and mapped. The caught adult and larval mosquitoes should be identified using morphological characters and parity rates should be established. Adult specimens should be analysed for P. falciparum and P. vivax sporozoites using the ELISA method. The annual inoculation rate and vector density can then be estimated for all the villages and GIS extrapolations developed for the whole of the hills.

To further refine the maps it would be necessary to describe the dispersal range of the main vectors. To investigate this several breeding sites for the main vectors which are well defined and focal could be identified for further studies of the dispersal of the adult mosquitoes. With such additional information it would be possible to develop high resolution risk maps for the individual villages so interventions could be targeted to selections of high risk households in the villages.
Resting and feeding behaviour of the main malaria vectors.
To get a detailed understanding of when and where the transmission occurs it would as well be beneficial to do more detailed studies on the resting and feeding behaviour of the main vector species. This could be done by employing a range of trapping methods in high transmission areas both indoors and outdoors and in the different associated habitats like animal shelters. To get a detailed understanding of the feeding and resting behaviour blood-fed mosquitoes should be analysed for blood meal source using a direct ELISA method. Further local risk factors should be identified such as increased risk of exposure caused by type of house construction, presence of domestic animals etc..

Zooprophylaxis using domestic animals.
The entomological findings also highlight that the mosquito vectors are highly zoophilic and prefer to rest near the animal shelters. This behaviour could be used to interrupt transmission by locating the animal shelters away from the human settlements or, even better, at a location between the houses and the most prominent breeding sites. This should be investigated on a small scale describing the effects on the behaviour of different mosquito vector species and the transmission dynamics.

Targeting of vector breeding sites
The entomological data suggest that most transmission takes place outside the houses. This needs further investigation, but it is possible that as much as 80 % of the transmission takes place outdoors. This limits the usefulness of traditional vector control measures like residual spraying and impregnated mosquito nets. Previous evidence suggest that the main vectors are An. maculatus and An. balabacensis; the effect of specific targeting of their breeding sites should be tested. There are three suggested ways to limit the breeding sites of these species. The main breeding site for An. maculatus are found in the 1,2,3,4 order streams. The streambed pools could be eliminated by flushing the stream systems using mini-dams or barrages or they could be treated with bacterial larvicide’s according to a well designed fixed time schedule or based on early warning indicators. The larviciding should obviously be focused to the stream beds in or very near the villages and could be done by trained local people. Eliminating the breeding sites of An. balabacensis may be more difficult as it prefers to breed in small shaded pools and tiny streams under the canopy. Larval surveys in the endemic villages could, however, identify the most productive areas and these could be eliminated by subsoil drainage and bacterial larviciding.

It is recommended that both flushing and targeted larviciding are investigated at a small scale including careful monitoring of the adult and larval mosquito populations. If successful and affordable they could be incorporated in the local intervention strategy.

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Annex 1 Elevation map of the Menoreh Hills in Central Java
Annex 2 Malaria incidence in the four most endemic parts of the Menoreh Hills area
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Annex 1.

ALTITUDINAL MAP OF MENOREH HILL - YOGYAKARTA
CENTRAL JAVA

Source:
1. Contour line digitation with altitude interval 100 m.

Universal Transverse Mercator Projection (UTM) Zone 49 M.

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Annex 2.

ANNUAL PARASITE INCIDENTS (API) MAP OF FOUR SUBDISTRICT IN MENOREH HILL-YOGYAKARTA CENTRAL JAVA 1996-2000

LEGEND:
- Beyond The Study Area
- River
- Road
- Railway

Source:

Universal Transverse Mercator Projection (UTM) Zone 49M

WORLD HEALTH ORGANIZATION (WHO)
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Annex 3.

DRAINAGE PATTERN MAP OF MENOREH HILL - YOGYAKARTA CENTRAL JAVA

LEGEND:
- District City
- Subdistrict City
- Case Village
- Province Boundary
- District Boundary
- Subdistrict Boundary
- Road
- Railway
- Primery River
- First River Order
- Second River Order
- Third River Order
- Fourth River Order
- Fifth River Order
- Coast Line

Source:
1. Interpretation of Aerial Photograph, 1:25,000, 1992.

UNIVERSAL TRANSVERSE MERCATOR PROJECTION (UTM) ZONE 49M

PUSPICS, FACULTY OF GEOGRAPHY, GADJAH MADA UNIVERSITY
WORLD HEALTH ORGANIZATION (WHO)
source:
1. malaria bloods survey, july-september 2000
2. topographic map, 1:50.000, 1963.

Universal Transverse Mercator Projection
(UTM) Zone 49 M

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WORLD HEALTH ORGANIZATION (WHO)
Annex 6.

MOSQUITO SPECIES TYPE AND DISTRIBUTION MAP OF EIGHT VILLAGES IN MENOREH HILL-YOGYAKARTA CENTRAL JAVA 1999-2000

LEGEND:
- Beyond The Study Area
- River
- Road
- Railway
- Case Village

Source:

Universal Transverse Mercator Projection (UTM) Zone 49M

WORLD HEALTH ORGANIZATION (WHO)
Annex 7.

MOSSQUITO DENSITY MAP OF EIGHT VILLAGES IN MENOREH HILL-YOGYAKARTA CENTRAL JAVA JULY,AUGUST, SEPTEMBER 2001

LEGEND:
- Beyond The Study Area
- River
- Road
- Railway

Source:

Universal Transverse Mercator Projection (UTM) Zone 49M

WORLD HEALTH ORGANIZATION (WHO)
Annex 8.

MAPS OF SUSCEPTIBILITY TO MALARIA, SELO TIMUR VILLAGE, KOKAP SUB DISTRICT, KULON PROGO DISTRICT

LEGEND:
- Roads
- River
- High Susceptibility Areas of Malaria
- Medium Susceptibility Areas of Malaria
- Low/Non Susceptibility Areas of Malaria
- Settlements

Sources:
1. Land Use Map From Interpretation Small Format Aerial Photograph, Selu Timur Village, Kokap Sub District, Kulon Progo District.

Scale 1: 1:11,500

UNIVERSAL TRANSVERSE MERCATOR PROJECTION (UTM) ZONE 49S, DATUM WGS84

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Annex 9.

MOST MALARIA PRONE AREAS IN THE MEROHEH HILLS (>200M) - YOGYAKARTA CENTRAL JAVA

LEGEND:
- District City
- Subdistrict City
- Case Villages
- Province Boundary
- District Boundary
- Subdistrict Boundary
- Road
- Railway
- River
- Main malaria prone area
- Non Main Habitats
- Settlement

Source:
1. Interpretation Of Aerial Photograph 1 : 25.000, 1996.
3. Stream Pattern Map 1 : 50.000.
4. Land Use Map 1 : 50.000.
5. Elevation Map 1 : 50.000.

Universal Transverse Mercator Projection (UTM) Zone 49 M

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Annex 10.

PRESENT MALARIA SUSCEPTIBLE AREAS IN THE MENOREH HILLS - YOGYAKARTA CENTRAL JAVA

LEGEND:
- District City
- Subdistrict City
- Case Villages

Province Boundary
District Boundary
Subdistrict Boundary
Road
Railway
River
High Susceptibility
Medium Susceptibility
Low Susceptibility
Settlement

Source:
1. Interpretation Of Aerial Photograph 1 : 25,000 , 1996.
3. Stream Pattern Map 1 : 50,000.
4. Land Use Map 1 : 50,000.
5. Elevation Map 1 : 50,000.

Universal Transverse Mercator Projection (UTM) Zone 49 M

WORLD HEALTH ORGANIZATION (WHO)
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