

MALARIA IN INDONESIA: A SUMMARY OF RECENT RESEARCH INTO ITS ENVIRONMENTAL RELATIONSHIPS

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Abstract. A review of the literature was carried out to evaluate malaria and its environmental relationships. Research, in 6 parts of Indonesia, addressed the relationship between malaria incidence and physical and socioeconomic environmental factors, using longitudinal and cross-sectional approaches. Physical factors, which are generally important for malaria, included rainfall, mosquito breeding and resting sites, their distance from human habitation, and elevation, though the latter was not statistically significant. Housing conditions were occasionally important. Social and economic factors of importance were income, education, use of bednets and pattern of outdoor activities, especially at night. Use of repellents, mosquito coils and sleeping arrangements were significant in some of the studies.

INTRODUCTION

Malaria is a mosquito-borne parasitic disease of global concern with 1.5 to 2.7 million people dying each year and many more suffering from it (WHO, 2000). Malaria in humans is caused by a protozoon of the genus *Plasmodium*. Most malaria is caused by *P. vivax*, however the worst type which causes the most deaths is *P. falciparum* (Oaks *et al*, 1991; Chin, 2000). There has been a world-wide resurgence of malaria, which appears to be related to a number of factors. These include the rapid spread of the resistance of malaria parasites to the quinolines (WHO, 1996), environmental changes, which may result in new mosquito breeding sites, and civil unrest, which may lead to people moving to areas of high malaria transmission, as well as voluntary migration of non-immune populations to areas with malaria (Nchinda, 1998).

Malaria in Indonesia

Malaria is a major public health problem in Indonesia with 6 million clinical cases and 700 deaths each year (Laihad, 2000). In 1998, it was reported that 46.2% of the total Indonesian population of 210.6 million lived in malaria endemic areas (Ministry of Health and Social Welfare, 2001). Laihad (1999) estimated that 70 million people in Indonesia lived in high-risk ma-

laria areas. Recent outbreaks and re-emergence of malaria in places which previously had been declared to be malaria-free require a re-assessment of the current national malaria control strategy. However, relatively little is known about its epidemiology in Indonesia (Marwoto, 1987).

Malaria transmission requires the presence of vectors. There are 80 *Anopheles* mosquito species found in Indonesia, of which, 24 are potential malaria vectors (Ministry of Health and Social Welfare, 2001). Those vectors are distributed throughout Indonesia, depending on the type of breeding site, and include *An. sudaicus*, *An. subpictus*, *An. barbirostris*, *An. maculatus*, *An. aconitus* and *An. balabacensis* (Harijanto, 2000). All types of malaria are present in Indonesia (Laihad, 2000).

Important factors in malaria transmission in Southeast Asia include environmental change (physical, biological and social, the latter including population movement) (De Las Llagas, 1985). Oemijati (1992) identified environment as important to malaria transmission in Indonesia, but little has been published on this aspect. The economic crisis has forced the government to reduce funds allocated to the health sector (Gani, 2000). Prior to the crisis, the health budget was US\$5.00/capita/year. The budget for 1999-2000, allocated for health was only US\$1.29/capita in North Sumatra, US\$0.90/capita in South Sumatra and Jambi and US\$2.20/capita in East Nusa Tenggara (Gani, 2000). The resources for malaria control are, therefore, very

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limited and most vector control programs, can be done only when outbreaks occur (Laihad, 2000).

To help manage the malaria problem, good information is needed regarding the relationship between malaria and environmental factors. This could facilitate planning in the use of scarce resources to specific areas which provide the maximum public benefit.

Our objectives are to integrate, summarize and discuss the range of malaria scenarios from six research projects. The paper first compiles a brief overview of the literature, focusing on physical and socioeconomic relationships (full critical reviews are in the original documents). Then it outlines the methodology and experimental designs, for the 6 projects, presents a summary of the results, with selected examples, and discusses the general findings.

Overview of the literature

Malaria occurs in an environmental context. The environment consists of physical, social, economic and cultural factors, including the effects of human disturbance (Gilles, 1993). The latter is especially important for malaria incidence. Environment affects the capacity of vectors to transmit the malaria parasite from one person to another (Najera, 1999), so environmental changes are likely to have an impact on malaria incidence (Patz *et al*, 2000).

Physical environment

Temperature, rainfall, relative humidity and wind patterns and their changes, such as the El Nino effect (Couper-Johnston, 2000), are factors which have an important impact on vector density, the vector's reproduction habits, longevity, development and survival of the pathogen (Martens *et al*, 1995; Zwerver *et al*, 1995; Aron and Patz, 2001).

Temperature plays a fundamental role in the rate of multiplication of the parasite in mosquitos (National Research Council, 2001) and directly influences the mosquito development, gonotrophic cycle and longevity, as well as the duration of the extrinsic cycle of the *Plasmodium* parasite. As a general rule, in warmer temperatures the mosquitos develop more rapidly and feed more frequently and the parasite develops earlier in the mosquito life cycle and multiplies more rapidly (National Research Council, 2001).

Even small temperature fluctuations can lead to increased malaria incidence and a very high temperature can kill the mosquito, parasite or both (UNEP and WHO, 2001). Ijumba and Linsay (2001) found large numbers of anopheline vectors at very high temperatures (above 40°C) but little or no malaria in children. This was probably because the heat limited the parasite. Lower temperatures can be a barrier for mosquito and parasite development. Where the mean monthly temperature is less than about 16°C, malaria is likely to be absent, even in the presence of anophelines, because it is too cold for the parasite to develop (Bailey, 1982; MARA/ARMA, 1998). Although low temperature may inhibit mosquito development, malaria transmission can still occur at temperatures below 20°C because the anophelines often live in houses, which tend to be relatively warm (Molineaux, 1988; Martens *et al*, 1995). The optimum temperature for the parasite extrinsic incubation period is about 20°-27°C (MARA/ARMA, 1998).

Rainfall influences malaria transmission by providing mosquito breeding places (Reid, 2000) and increasing humidity, which improves mosquito survival rates. The relationship between malaria and rainfall can be complex. Although water is necessary for larval development (Burman, 2000; Aron and Patz 2001), heavy rainfall during the wet season may flush mosquito larvae away. Heavy rainfall followed by drought can result in ephemeral pools which may also provide mosquito habitats (Harrison, 1978; Oaks *et al*, 1991). In contrast, a prolonged dry season followed by flooding can increase malaria incidence if it leaves remnant mosquito breeding places (Hien, 1999). A prolonged dry season can decrease mosquito numbers by reducing breeding sites and also reduce malaria incidence (Denis, 1999).

Relative humidity does not directly affect the parasite but may affect the activity and survival of anopheline mosquitos. If the average relative humidity is below 60%, the life of the mosquito may be shortened to less than the extrinsic incubation period (about 2 weeks) so that there is no malaria transmission (Gilles, 1993).

Wind may play both a negative and positive role in the malaria cycle. Anopheline mosquitos are not usually found more than 3 km from their breeding places, however strong seasonal

winds may carry them up to 30 km or more (Gilles, 1993). Normally, females (the disease vector) disperse further than males (Bruce-Chwatt, 1993). Wind also tends to suppress mosquito flight, and hence biting (Snow, 1980; Bidlingmayer *et al*, 1999) concluded that the maximum air speed capabilities of *Anopheles* in an upwind approach to their hosts were approximately 1.0 to 1.2 m/s.

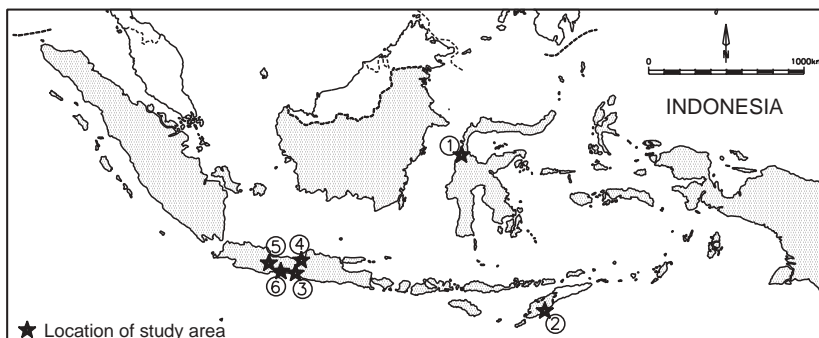
Socioeconomic factors

The interactions between social and economic factors and malaria incidence are complex. Human activities and occupations may bring people into contact with infected anopheline mosquitos (Krause, 1998). The type of housing is important; whether it is mosquito-proof. Human behavior, such as sleeping indoors or outdoors, clothing habits, use of bed nets, repellent use, mosquito coil use, and population movement can affect malaria transmission (Orlov and Kondrashin, 1989).

The relationship between malaria and occupation in Southeast Asia is unclear in the literature and several authors report no significant relationship [Sudathip (2002) in Thailand; Burton *et al* (2002) in the Philippines; Barker (2002) in Vietnam].

House construction has an effect on malaria infection. The general relationship is that malaria incidence is higher in houses of flimsy construction which permit the entry of mosquitos (Thompson *et al*, 1997, Gunawardena *et al*, 1998). The location of human settlements in relation to mosquito breeding places is also an important factor in malaria transmission, increasing with increased proximity (Gilles, 1988; Thompson *et al*, 1997, Gunawardena *et al*, 1998).

Bednets are considered essential by the WHO in control programs because they provide protection from mosquitos (WHO, 2001) and may have a significant effect in reducing the incidence of malaria (Smutylo *et al*, 1996; Lengeler *et al*, 1998).



Authors

1 Papayungan (Sulawesi, Donggala); 2 Ndoen (W. Timor); 3 Prabowa (Kebumen); 4 Saikhu (Central Java); 5 Anto (Pamotan Village); 6 Hutajula (Cilicap)

Fig 1—Location of study areas.

The key issues explored in the present Indonesian analysis included the complex role played by rainfall, relative humidity, wind and temperature, and the effect of socioeconomic factors, including the location of settlements with respect to anopheline mosquito breeding habitats.

METHODS

Study areas and project descriptions

The location of the study areas is shown in Fig 1. The scope of the studies is shown in Table 1. The study areas represent a range of malaria situations and environments, including both coastal and hill country. The climate is characterized by high temperatures and heavy rainfall, especially during October-March, and the relative humidity was generally high. The minimum temperature in the coolest area (West Timor) was 16°-17°C, with a maximum of 26°-28°C, and a relative humidity of 63-97% (mean 83-89%). In Central Sulawesi, the temperature range was 21°-38°C, and the relative humidity was 72-82%. In Central Java, the temperature range was 24°-32°C, and the relative humidity was 80-90%.

Conceptual framework

The overall aim of the projects was to evaluate the relationship between malaria incidence and environmental factors. Environment was broadly defined to include physical and socioeconomic factors, limited by the availability of data on these. The conceptual framework is shown in Fig 2.

Data sources

For the cross-sectional studies, the data were provided by the Benefit Evaluation Study (BES) of the Intensified Communicable Diseases Program in Indonesia 2001. This was a stratified random survey which covered the whole of Indonesia and surveyed a wide range of diseases, collecting data on disease incidence and variables, such as housing type (walls, number of rooms, etc), cooking methods, behavior (such as the use of repellents), activities outdoors and indoors by time of day, and mosquito breeding and resting habitats.

The longitudinal studies obtained data for malaria and climate variables from government

agencies and field observations.

Additional observations were made by field observations using standard scientific methodologies, such as wind speed meters, larval surveys using dippers, and others.

Data analysis

The general hypotheses were that there is not (H_0) or is (H_1) a relationship between malaria incidence and the variables being researched.

SPSS version 10.00 for Windows was used for data analysis. After describing the data, with mean, median, mode, and standard deviation, the hypotheses were tested using ANOVA and regression for continuous data and chi-squared

Table 1
Summary of projects (* indicates aspects researched).

	Saikhu (2002) Central Java Province	Prabowa (2002) Central Java 1999-2001	Hutajulu (2002) Central Java	Papayungan (2002) Central Sulawesi	Anto (2002) West Java 1999-2001	Ndoen (2002) West Timor 1996-2000-
Malaria incidence (Independent variable)			(including repeated infection)	(including repeated infection)		
Spatial resolution						
Province	*					
District	*	*		*		*
Village		*	*		*	*
Study type						
Longitudinal ^a		*			*	*
Cross sectional ^b	*		*	*		
Dependent variables						
Climate/altitude						
Rainfall		*			*	*
Relative humidity		*			*	*
Temperature		*			*	*
Wind					*	
Altitude						*
Mosquito related						
Breeding places	*		*	*		
Resting places	*			*		
Mosquito numbers/biting rates			*			*
Socioeconomic						
Age, sex	*			*		
Occupation	*		v	*		
Education	*			*		
Knowledge (about malaria)		*			*	
Housing condition	*		*			
Activity	*		*			

^aData from government sources, local offices and field work.

^bBenefit Evaluation Study (BES) (2001).

analysis for categorical data with frequencies.

Because of the delay between rainfall, the flooding of breeding habitats, and the extrinsic incubation period (in the mosquito) which requires an average of two weeks, and the intrinsic incubation period (in the human) which requires an average of two weeks, the researchers included a lag time of 1 month between rainfall and malaria incidence.

Geographic Information Systems (MAPINFO and Arc View) were used only for mapping purposes (3 of the 6 studies used GIS in presenting the results).

RESULTS

The results are summarized in Tables 2 and 3. Only examples are included in the text for discussion.

Physical environment

Table 2 summarizes the results of the studies which considered the physical environment (and mosquitos).

Climate and altitude

Rainfall results showed no clear pattern. In some cases there were positive associations with malaria and/or mosquito density. In one study in

Table 2
Results of physical environment studies and their relationship with malaria. +and - indicate where the results are significantly positive or negative at p<0.05. Significant cells are shaded. D-District, V-Village. ns - not significant. RH-relative humidity.

Variable	Longitudinal studies			Cross sectional studies		
	Prabowa (2002) Central Java	Ndoen (2002) West Timor	Anto (2002) West Java	Saikhu (2002) Central Java	Hutajulu (2002)	Papayungan (2002) Sulawesi
Climate						
Rain	- (2 years only) with malaria (D) ns (V) and ns with mosquitos (V)	Malaria in dry season (District) - (Village)	+ with mosquitos			
RH	ns (D) slightly - with mosquitos (V)		ns			
Temperature	ns (D, V) and ns with mosquitos, (V)	- for some	ns			
Wind			-			
Altitude		850m -most malaria				
Mosquito related	ns mosquito #'s and malaria		mosquito #'s + with malaria			
Breeding places:				ns		+
Swamp				ns		+
Spring						+
Pond				+	+(distance)	+
Rice paddy						+
Brackish				ns		+
Resting places:						
Bush				+		ns
Yard				+		+
Cattle/animal pens				ns		+

the Kebumen district the relationship was generally negative, although not always significantly so when the data were disaggregated by year (Prabowa, 2002).

Ndoen (2002) found malaria to be maximal during the dry season in West Timor, at the district level. At the village level, some correlation coefficients showed that rainfall had a positive correlation with malaria in 4 villages, though not in every year, indicating that malaria increased as rainfall increased. This study also showed a relationship between malaria incidence and altitude. Although not statistically significant, there were more cases at 850 m than at lower (or higher altitudes). This may be related to complex interactions between other variables, such as land cover and previous exposure of the population, as well as temperature and rainfall. The temperature was somewhat lower at higher elevations, but not enough to inhibit mosquito development, and rainfall was higher at higher elevations. In the West Java study, rainfall was significantly and positively related to mosquito density and the latter was also positively related to malaria incidence (Anto, 2002).

The West Java study by Anto (2002) also examined the effect of wind and found a negative correlation with mosquito density. This is a local effect that may be important in malaria transmission.

Mosquito density, breeding sites and malaria

At district and village levels, there were some significant relationships between mosquito breeding and resting sites and the incidence of malaria. Anto (2002) found a significant positive relationship between mosquito density and malaria incidence for Pamotan village. He also found that mosquito activity was at its greatest during late evening, night and pre-dawn. Prabowa (2002) found no significant correlation between mosquito density and rainfall, at the village level, for the 3 main vectors *An. aconitus*, *An. maculatus*, and *An. balabacensis*.

The Central Sulawesi project found significant positive relationships between mosquito breeding and resting sites. These included swamps, springs, rice fields, ponds, and brackish water breeding sites and yards and the presence of cattle for resting/feeding sites (Papayungan, 2002).

The results of the Central Sulawesi research were also supported by those in Ujang Gagak village, Central Java (Hutajulu, 2002). Hutajulu found that the distance of the dwelling from a mosquito breeding pond was negatively related to malaria incidence.

The Central Java study by Prabowa (2002) examined the same variables but the only significant breeding sites were ponds and the main effects were from the presence of bush and or a yard as resting sites, but not from animal pens.

Demographic and socioeconomic factors

Three studies considered demographic and socioeconomic factors, two at the district and one at the village level. Table 3 summarizes the results of the socioeconomic research.

None found a significant relationship between malaria and gender. Age was significant in 2 studies, with most cases in the working age group (Papayungan, 2002; Saikhu, 2002). Occupation was broadly divided into farmers or non-farmers. There were more cases of malaria in the farmer category, but only one, in Central Sulawesi, was statistically significant (Papayungan, 2002). Middle income levels and lower educational levels (Papayungan, 2002; Saikhu 2002) were significantly associated with malaria.

Knowledge about malaria and its causes, symptoms, and transmission, was high, and was generally not significantly related to the incidence of disease [knowledge of transmission and malaria types was significantly associated with malaria in one study (Saikhu, 2002)]. Hutajulu (2002) found that a large number of the respondents had repeated infections. These were significantly related to the factors recorded (Table 3).

Housing characteristics were variable in their relationship with malaria incidence. At the district level in Central Java, there was significantly less malaria in homes built of brick (Saikhu, 2002). This may be related to income or occupation. At the village level, in Central Java, there was no significant association between house type and malaria, though screens were associated with a reduced incidence of malaria (Hutajulu, 2002).

Patterns of activity at the household and individual levels generally were related to the incidence of disease. Important factors included using mosquito repellents and bednets. Wear-

Table 3
Summary of the socio-economic results (including previous malaria history).

Variables	Akhmad Saikhu Central Java Province	-Bangkit Hutajulu Ujung Gagak village Central Java	Meisy Papayungan Donggala, Central Sulawesi
Previous malaria		Most had previous malaria	Most had previous malaria
Socio-economic			
Age	Significantly more in age groups 16-60 years	ns	Significantly more in age group 15-54 years
Sex	ns	ns	ns
Education	Significantly associated with elementary education only	ns	Significantly associated with elementary education only
Occupation		ns, (but more farmers)	Significant (more malaria in farmers)
Income			Significantly associated with middle income
Knowledge about malaria			
Transmission	ns		
Cause	ns		ns
Symptoms	ns		
Know about screens, coils, bednets, etc	ns (except knowing about mosquito coil p<0.05, if not knowing then 1.5 times as likely to have had malaria)		ns
Behavior			
Yard at night for :			
1.Sleeping	significant (increased cases)		Sleeping in plantation-increased malaria
2.Use for toilet	significant (increased cases)		
Wearing long sleeves/pants	significant (decreased cases)		ns
Use of:			
1.mosquito coils/repellent		significant (fewer cases)	ns
2.bednets		significant (fewer cases)	ns
IR spray		ns	
Housing condition			
Walls	significant (fewer cases with brick walls)	ns	
Screens	ns	significant (fewer cases)	

ing long sleeves/pants reduced the risk of malaria in one study (Saikhu, 2002), whereas using the yard at night for sleeping or other activities increased the risk of malaria, though not consistently so.

In summary, we can review the variables explored in the original conceptual framework (Fig 2) and identify those which were found

to be important determinants of malaria for the areas studied. These are highlighted in Fig 3.

DISCUSSION

District and village level studies

At the district level, the research by Prabowa (2002) found a generally negative rela-

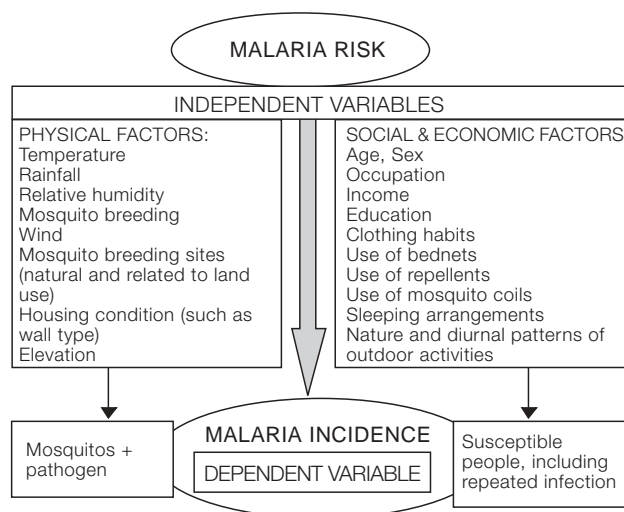
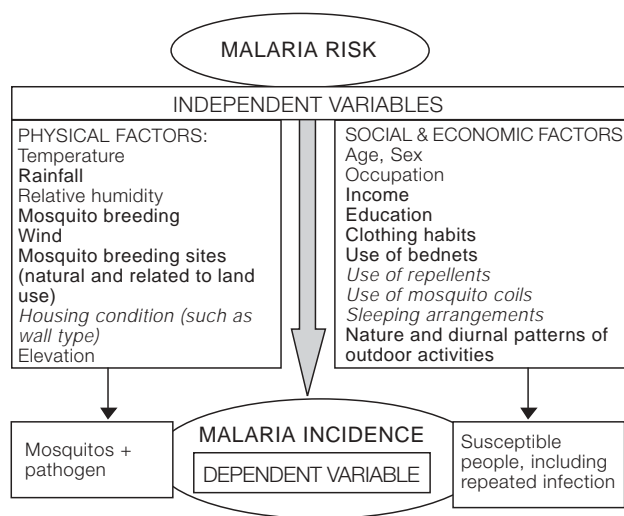


Fig 2—Integrated conceptual framework.



Bold indicates generally significant
Italics indicates sometimes significant

Fig 3—Conceptual framework with important variables highlighted.

tionship between rainfall and malaria, which he also found at the village level in one location. In another study there were conflicting results between the district and village level of the analysis. Ndoen (2002), at the village level in Timor Tengah Selatan (TTS) district, found a significant positive relationship with rainfall in 4 villages, although not in all years. These were at both low

and high altitudes, so altitude and its effect on rainfall did not explain this result. The difference between malaria patterns at the district level and the village level may be due to many factors. First, the scale of the study may affect the results, as malaria was distributed unevenly between the villages. Second, the data collected by the health centers was possibly insufficient to give a complete description of malaria prevalence in the villages. Third, malaria is influenced by locally specific conditions. It is very difficult to have a clear pattern of malaria transmission without a monitoring system at an appropriate level of resolution.

Cross-sectional and longitudinal studies

The cross-sectional approach takes a single snapshot in time whereas the longitudinal ones consider a period of time. Cross-sectional data at the national level (BES data) provide a broad overview but may not have sufficient detail for local studies. The disease incidence type, epidemic or endemic, is related to the pattern over time. There is much value in a longitudinal survey, but there may be difficulty in obtaining comparable data; missing records may be a problem.

The three cross-sectional studies showed some contrasting results. The most different were those from Central Sulawesi (Papayungan, 2002) and Central Java (Saikhu, 2002). The former found many more significant associations between malaria and the mosquito breeding place, whereas the latter found significance mainly in mosquito resting sites. These differences may be attributed to the contrasting environments, different vectors and their behaviors. Patterns may not be consistent over time. For example, the longitudinal research by Ndoen (2002) found marked differences in the relation between rainfall and malaria at the village level. This varied from year to year. Similarly, Prabowa (2002) found differences between years in the effect of rainfall on malaria, with some being significant and others not.

The following paragraphs discuss some of the significant variables found in the present projects.

Rainfall

For mosquito density and rainfall, there were different results in the different areas, Anto (2002), in West Java, found a significant posi-

tive relationship with rainfall, whereas Prabowa (2002) in Central Java found no relationship. Anto's (2002) study areas covered a wide range of terrain types from estuary to hill country.

There appear to be four scenarios relevant to mosquito breeding in places such as Indonesia where temperature is not a limiting factor. First, high rainfall may create water bodies suitable for the disease vector anopheline mosquitos. This situation was found in one study which also considered mosquito breeding (Anto, 2002). This is supported by research by Taylor and Mutambu (1986), Koram, (1991) (cited in Aron and Patz, 2001) and Burman (2000). WHO/OMS (2000) and Couper-Johnston (2000) reported that the El Niño cycle is associated with an increased risk of malaria.

Second, heavy rainfall followed by drought may leave residual water bodies sufficient for successful emergence of mosquitos. There was no evidence of this in these studies. Third, prolonged drought may result in the construction of artificial water containers for irrigation or water supply and these may breed mosquitos. Although there was no direct evidence of this, it was noted that the creation of ponds following mangrove clearing did appear to be related to increased malaria (Anto, 2002) and the proximity of the ponds was similarly related to increased malaria (Hutajulu, 2002; Papayungan, 2002). Local literature provides some support. In Timor Tengah Selatan (TTS) district in Indonesia, Nahak (2000) found that the peak malaria incidence was from June to August (the drier season). Haryani and Mortono (1991, cited in Nahak, 2000) found the highest density of *An. barbirostris*, the main vector of malaria in Timor Island, during a similar period. Because TTS district experiences a lack of water during the dry season the government has built ponds and irrigation systems, which can provide breeding places for mosquitos (Aron and Patz, 2001). Drought, if not mitigated by water provision, is unlikely to lead to increased malaria.

Fourth, heavy rainfall may flush out the wetland systems removing any larvae and there will be little breeding and little malaria transmission from those wetlands. The negative correlation between rainfall and malaria found by Prabowa (2002) may be related to this fourth situation. Many researchers have also found that malaria may be absent in the wet season (several ex-

amples are cited in Aron and Patz, 2001).

Relative humidity and temperature

The present reviewed-studies found no significant relationship between relative humidity, temperature, and malaria. This is consistent with the findings of other researchers who reported that a relative humidity of at least 60% is the most conducive for the mosquito (Carrington, 2001); this value is generally exceeded in all the study areas. Similarly, temperatures were usually in the optimal range of 20°-27°C for mosquito and pathogen development (MARA/ARMA, 1998) and hence no relationships were found,

Altitude

From the literature, the issue of altitude appears to be an important one. In the present reviewed-research there was only a weak association with altitude in one of the study areas where the greatest incidence of malaria was at 850 m (Ndoen, 2002). Although MARA/ARMA (1998) noted that malaria incidence is generally lower in highland areas due to the lower temperature, this is not always the case. In Africa, recent evidence suggests that malaria incidence increases in highland areas. This may be a result of increasing temperatures and Martens *et al* (1995) suggested that, at higher altitudes, an increase in temperature of several degrees centigrade can increase the potential transmission of malaria. Other reasons for differences in malaria in highland areas include different vegetation (Lindsay and Birley, 1996; cited in UNEP and WMO, 2001), which is conducive to *An. barbirostris*, one of the main vectors of malaria. Another possible factor is the migration of mosquitos from lower to higher altitudes during warm and rainy weather (Leeson, 1931). This has implications for the effect of global climate change on malaria.

Ndoen's (2002) study also found variability in malaria incidence within each year and from year to year, suggesting that it is unstable. In unstable areas, the dominant parasite is *P. vivax*. This species is commonly related to relapses (Oaks *et al*, 1991). Hutajulu (2002) found that 65% of the respondents in Ujung Gagak village had suffered from malaria more than once, and some of them from several occurrences. Papayungan's study (2002) found a similar pattern.

Effects of environmental change on mosquito breeding

Anto (2002) observed in the Pamotan village-study that mosquito breeding habitats were increasing and that this might explain the resurgence of malaria. Deforestation has occurred for various purposes including agriculture, sugar production, and domestic firewood. The resultant ponds and algal growth increase malaria vector breeding places (WHO, 1987; Takken *et al*, 1990). The Vector Control Field Station for Pamotan village reported larvae of *An. sundaicus* in non-irrigated rice fields in 2000, following deforestation. The ponding was exacerbated by tide water as well as rainfall, making the brackish area suitable for the larvae of *An. sundaicus*. This is likely to contribute to increased malaria transmission. Wernsdorfer and McGregor (1988) noted that tides and their interaction with coastal lands affect breeding of both salt-water and fresh-water species. This is also consistent with a WHO study (1996) which reported that sea-level rise and increased coastal flooding may result in more brackish water, which would favor vector species such as *An. subpictus* and *An. sundaicus*.

Fish ponds are also related to mosquito development. If not properly maintained or if abandoned, they become malarial mosquito breeding places (Laihad, 2000). WHO (1987) reported that construction of fish ponds along the coastal areas in Java-Bali and the outer islands has increased breeding places and prolonged the breeding season of *An. sundaicus*, thereby increasing the malaria endemicity of the local population.

Social and economic factors

The general conclusion from the studies which considered social and economic factors showed that low levels of education and low-middle income tended to be related to higher incidences of malaria. This probably relates to the quality of housing and occupation. Flimsy dwellings and the occupation of farming have an increased risk of malaria. In contrast, Hutajulu (2002) found that dwelling construction was not significantly associated with malaria, and considered that this was because most dwellings allowed entry of mosquitos regardless of their gross structural type. The high intensity of malaria transmission meant that people could be

infected indoors or outdoors. Behavioral risk factors included night-time activity outdoors. Malaria vectors are most active between dusk and dawn and this contributes to malaria transmission. Other behavioral factors which are in agreement with the literature include the use of bednets, repellents, wearing long sleeved shirts and long pants.

Other factors

Migrations, urbanization, improved transportation (WHO, 1987), refugees, travelling, and movement of agricultural labor, are normal activities of humans that can cause imported malaria cases (Martens and Lisbeth 2000; WHO 2002). The movement of infected people from areas where malaria is endemic to areas where the disease has been eradicated has led to a resurgence of disease. For example, Pamotan villagers farm in malarious areas; when they return, existing anopheline vectors may become infected by the *Plasmodium* pathogen and hence increase transmission (Anto, 2002).

Recommendations and limitations of the studies

Each piece of research led to recommendations specific for the research area. There were some issues common to all. They related mostly to the management of the disease, which could be improved by increasing the coordination of health and mosquito control services. In turn, these need to be informed by accurate data (disease, mosquitos, and environmental data) and effective management and display of information. They made recommendations related to remedying the most important limitations in the research environment. These are summarized below.

Limitations related mainly to data reliability, its availability, the time frame of the survey, and the technological constraints.

The number of malaria cases in Indonesia may be under-reported if sourced only from community health centers, as these do not include cases detected by other facilities, such as private practitioners and hospitals. Different methods of diagnosis may result in misdiagnoses, since besides using laboratory examination, clinical symptoms are used (which may appear similar to other diseases). This can lead to over-reporting, which may also occur if recurrences of

the disease are counted as new cases.

To fully assess the dynamics of the disease requires time series data. Cross-sectional (BES) data only describes the malaria prevalence at a point in time and, therefore, it is not suited to exploring temporal patterns. A longitudinal study, including entomological data, would help avoid this problem provided the data quality is consistent over the time period.

Data availability is an issue. For the environmental data, the limited availability of, for example, meteorology stations, results in climate data unsuitable for the scale needed to assess disease relationships. Complex factors influence malaria transmission, but research can only investigate those factors for which data can be obtained. There is some scope for the use of surrogate data, such as remotely sensed data, to indicate suitability for mosquito breeding. This needs access to funds and computing facilities (hardware and software). This leads us to the issue of GIS. The problems with using GIS for malaria management in Indonesia have been reviewed by Sipe and Dale (2004). For the study areas described here, digital data were limited and hard copy maps suffered from not having some of the basic information needed, such as projection, scale or date (the latter is important for land use). To address the problem of scale, Prabowa (2002) attempted to generate more detailed temperature data from a single known station by applying a formula based on the temperature lapse rate with altitude.

In conclusion, this review has identified areas where the results support/contrast with findings reported in the literature, as well as noting consistencies and contrasts between the studies themselves. This shows that the results may differ even when using the same data source (BES). This may reflect the heterogeneity of the Indonesian environments and its malaria patterns.

On a positive note, variables likely to be good predictors of malaria and its mosquito vectors have been identified. Rainfall is generally a significant factor, but what is important is to identify which of the scenarios is occurring: rainfall, rain after drought, drought after rain (which create breeding places), flushing rain (little malaria), and drought (little malaria unless open water is artificially provided). This involves collecting reli-

able data at appropriate time and spatial scales. Other relevant predictors include the presence and location of mosquito breeding and resting sites (with respect to human activity).

Variables which can be used to help reduce or prevent malaria have also been identified from the larger list of variables observed. These include behaviors that reduce night-time activity outdoors, wearing covering clothing, using repellents, bednets, and mosquito-proofing homes.

Finally this review has made the research projects available to a wide audience which might otherwise have not had easy access to such a large amount of information.

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