MALARIA RISK FACTORS IN AN ENDEMIC REGION OF SRI LANKA, AND THE IMPACT AND COST IMPLICATIONS OF RISK FACTOR–BASED INTERVENTIONS


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Abstract. In an 18-month study of malaria in a population of 1,875 residents in 423 houses in an endemic area in southern Sri Lanka, the risk of malaria was found to be 2.5-fold higher in residents of poorly constructed houses than in those living in houses of good construction type. In residents of poorly constructed houses but not in others, the risk was even greater when the house was located near a source of water that could act as a potential breeding place for malaria vector mosquitoes (P = 0.0001). Based on previous findings that confirmed that house construction type was itself a risk determinant, and not merely a marker of other behavioral factors, we have estimated the potential impact of two feasible interventions to reduce the risk of malaria: 1) the imposition of a buffer zone of 200 meters around bodies of water from which houses of poor construction were excluded, which was estimated to lead to a 21% reduction of the malaria incidence in the overall population and a 43% reduction in the relocated community; and 2) the conversion of houses of poor construction type located in the buffer zone to those of a good construction type, which was estimated to lead to a 36% reduction in the incidence rates in the whole population and a 76% reduction in the residents of houses whose construction type was improved. Taking into consideration the cost to the Government of malaria prevention, we estimated the worth of a Government’s investment in improving house construction type. The investment in housing was estimated to be offset in 7.2 years by savings to the Government on malaria costs alone, and beyond this period, to bring a return on the Government’s investment by way of savings to the malaria control program.

Malaria is a major public health problem in Sri Lanka with almost 0.3 million infections being reported annually in its population of 17 million. The disease constitutes the fourth highest cause of hospital admission in the country, and its control costs as much as two-thirds of the national public health budget. Malaria has made a considerable impact on the health, economy, education, and general development of the population (Ministry of Health, Colombo, Sri Lanka, 1986, unpublished data). Although falciparum malaria was, except for occasional epidemics, a rarity in the past, both Plasmodium vivax and P. falciparum malaria are now prevalent in Sri Lanka. With at least half of the P. falciparum infections being at present resistant to chloroquine, malaria promises to be even more of a problem in the future.

One of the difficulties associated with achieving a reduction in the malaria incidence is that a combination of many diverse factors contribute to the maintenance of its transmission. These include environmental and geographic features of the area such as climatic factors, land use patterns, development of irrigation schemes, the movement and habits of people, and the creation of new human settlements in relation to development schemes. Malaria has now resurfaced on a global scale following major eradication and control programs of a few decades ago, which were based on powerful technical tools. This suggests that blanket approaches to delivery of these methods are wasteful, and calls for a re-examination of the principles of transmission on a micro-epidemiologic scale to identify risk factors and to formulate interventions that may have to be applied in a more focused manner.

Even in moderately endemic areas of the country, it is well known that malaria infections are not homogeneously distributed; some individuals and families are subject to repeated malaria infections while others experience no infections. In previous studies, we have shown that the malaria risk in endemic areas is greater in residents of poorly built houses than in those who live in well built ones. Although behavioral patterns of the residents of these two types of houses may also contribute to this difference in malaria risk, there are reasons to believe that construction type in itself contributed to the higher risk in poorly constructed houses because we have found that the poorly constructed houses harbor significantly higher numbers of indoor-resting mosquitoes than do the well built houses, which indicates that a higher human-mosquito contact rate must prevail within them. In the present study, we investigated house construction types and other malaria risk factors in an endemic community in Sri Lanka, and have estimated the impact of interventions based on the findings.

MATERIALS AND METHODS

Malaria in Sri Lanka, the study area, and population. Malaria is endemic and is unstable in the dry zone of Sri Lanka constituting approximately two-thirds of the land area of the country, with approximately half of the population being exposed to malaria. The Kataragama area in southern Sri Lanka (Figure 1), in which the study was conducted, is typical of the dry zone of the country, where the majority of the population, mainly rural peasants, are engaged in agricultural pursuits. The country experiences a major transmission season during the annual northeast monsoonal rains and a minor one during southwest monsoonal rains. Both parasite species (P. vivax and P. falciparum) are prevalent in the country with the former constituting about 60–70%
of the total malaria case load, and infections with either give rise to acute febrile episodes in persons of all age groups, as described in detail elsewhere. Infected persons attend malaria diagnosis and treatment facilities that are distributed throughout the endemic areas of the country and are easily accessed. The principal vector of malaria in Sri Lanka is Anopheles culicifacies, which is indoor resting, endophagic and exophagic, and primarily zoophilic in its habits. It breeds in clear, stagnant, or slow-flowing water such as margins of rivers and streams, and in rock pools that form during periods of drought, all of which are abundant in the study area. The inoculation rates of malaria in the study area averaged 0.5–1 inoculation per person per year. Malaria control activities conducted by the National Malaria Control Program, the Anti-Malaria Campaign, in the study area included early detection and prompt treatment of cases (the recommended regimen of radical treatment is 25 mg of chloroquine/kg of body weight and 1.25 mg of primaquine/kg of body weight given over a five-day period), and one application of residual insecticide spraying with malathion just prior to the commencement of the study. The use of impregnated bed nets validated by reconfirming geographic locations and demographically characterizing individuals in the study population. The villagers were mainly peasant farmers engaged in either Chena, a shifting-bush-fallow system of cultivation that is a traditional agricultural practice in Sri Lanka or in rice cultivation. In the more urbanized parts, they were engaged in small-scale trading activities. The villages were edged by typical dry zone forest (Figure 2) with dry, mixed evergreen vegetation ranging from thorny bushes to larger trees. A river, the Menik Ganga, provided a source of water for agriculture. One of the eight villages comprised an urban cluster located in the middle of the study area (Village 6 in Figure 2). Since endemic malaria is confined to the dry zone of Sri Lanka, this study area is in many ways typical of malaria endemic regions of the country with respect to the demography and the sociocultural aspects of its residents, as well as the geography and ecology, and the annual rainfall patterns that prevail in the area.

Ethical clearance was obtained from the Ethical Review Committee of the Faculty of Medicine at the University of Colombo. Informed voluntary consent was obtained from all adults, and parents or guardians in the case of children, for enrollment in the study. Implied consent was assumed in the case of patients seeking diagnosis and treatment facilities at clinics conducted by the Malaria Research Unit, University of Colombo.

**Recording and analysis of spatial information.** Aerial photographs (1993, taken at an altitude of 10,000 meters by the Survey Department, Sri Lanka) were enlarged to a scale of 1:5,000 (with real world coordinates). The exact locations of the houses, roads, land use, forest cover, and significant bodies of water such as rivers, small streams, and reservoirs were confirmed by the Geographic Reconnaissances carried out in the preparatory stage of the study. The maps were digitized and the nearest distances between each of the houses and bodies of water and the forest edge were obtained using the Geographic Information Systems ARCINFO package (Environmental Systems Research Institute, Inc., Redlands, CA) (Figure 2). In the case of static bodies of water, distances were measured to its edge; in flowing bodies of water, they were measured to the center of flow. All the houses in the study area were numbered and every house and individual residents in each house were assigned a unique identification number to enable the monitoring of malaria infections in the population.

**Case detection.** Since most malaria infections in Sri Lanka result in acute febrile illness, monitoring of malaria infections was carried out as previously described, mainly by passive case detection in which fever patients who present themselves for treatment were subjected to blood film examination and treatment either at our Malaria Research Station, which is located at the edge of this study area (Figure 2), or at the Government Hospital in Kataragama, which is about 3 km from the study area. Ninety percent of the malaria infections reported in this study were detected by this method. A series of six mass blood surveys were also performed at intervals of 2–3 months, at each of which approximately 80% of the population were screened for malaria by thick blood film examination. The remainder of the malaria infections (10%) were detected in this program. A diagnosis of malaria was established by demonstration of

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**Figure 1.** Map of Sri Lanka showing the climatic zones corresponding to malaria endemicity, major cities, and the location of the study area.
Figure 2. Map of the study area showing A, distribution of well constructed and poorly constructed houses and landmarks, and B, the buffer zone of 200 meters around bodies of water as described in the text. The inset in B indicates the boundaries of the eight villages.
malaria parasites on microscopic examination of thin and thick blood films stained with Giemsa stain, and this was subjected to routine quality control. We estimate that almost all malaria infections that occurred in the population irrespective of the individuals' socioeconomic status were recorded by us by these two methods because preliminary investigations carried out during the census survey in the area have shown that this population relies almost entirely on the two previously mentioned centers for the diagnosis and treatment of malaria.

House types and malaria incidence rates. All houses in the study area were categorized into two broad types according to house construction, using strict objective criteria based on the nature of the walls and roof, and the building material used for their construction, as we had described previously. Thus, houses that had incomplete and/or mud walls and roofs made of coconut palm thatch were classified as being of poor construction type (Figure 3A), and those with completely plastered brick walls and tiled or corrugated iron roofs as being of good construction type (Figure 3B). Houses with two or fewer residents were excluded from the analysis to avoid unstable incidence rates.

Definitions. A malaria infection due to either *P. vivax* or *P. falciparum*, as detected by microscopy, was considered a case of malaria. No attempt was made to distinguish between relapses and reinfections of *P. vivax* since very few relapses would have occurred due to the routine use of primaquine for the treatment of dormant parasite liver stages. Primaquine is administered over a five-day period at a dosage of 0.25 mg/kg of body weight/day. This regimen has been shown to be comparable with the same dose administered over a 14-day period and is recommended by the National Malaria Control Program. The incidence rate in a house was defined as the number of malaria infections that occurred in that house per single resident during the 18-month study period. The average incidence rate for a group of houses (e.g., of a particular construction type) was estimated as the mean incidence rates of the houses in that group. The incidence rate of a population was defined as the number of infections per person that occurred in that population during the 18 months of study.

RESULTS

Malaria risk in relation to house construction type. Of a total of 423 houses and 1,875 residents in this population, data pertaining to only 343 houses and its resident population of 1,744 were considered for this analysis; the rest of the houses had less than two residents each and were excluded from the analysis for statistical reasons. During the study period of 18 months, 1,579 malaria infections were detected in these 343 households, 913 of which were *P. vivax* and 666 *P. falciparum*. The malaria incidence rate (number of infections per person) in this population during the 18 months was thus 0.91. One hundred eighty-two of the 343 houses were of poor construction type, and 161 of the good construction type. The houses of good construction type tended to cluster around principal roads, whereas the poorly built ones were scattered generally over the entire area (Figure 2). Residents of this area were almost equally distributed between the houses of good (838) and poor (906) construction.

The malaria incidence rates in the populations resident in good and poorly constructed houses differed significantly (Table 1), being 0.51 and 1.27 infections per person, respectively. The risk of malaria was thus 2.5-fold higher in inhabitants living in the poorly constructed houses than in those living in houses of good construction type (95% confidence interval [CI] = 2.19, 2.93, *P* < 0.001). The average incidence rates in the two types of houses deduced from the incidence rates of individual houses were 0.46 and 1.27 infections per person per house in good and poorly constructed houses, respectively. A similar difference in malaria risk was also observed among the residents of the 80 houses that were excluded from this analysis because they had less than three residents; they comprised 46 houses of good construction and 34 poorly constructed houses in which the average malaria incidence rates were 0.3 and 0.79, respectively (relative risk = 2.61; 95% CI = 1.80, 3.78).

Since there appeared to be a clustering of houses of good construction type along a particular horizontal axis comprising mainly three villages numbered 3, 5, and 6 (as shown in Figure 2), while the poorly constructed houses were more generally distributed over the entire area, we considered the possibility that an environmental factor(s) in the area where the houses of good construction were predominant, rather than the house type itself, could have accounted for the lower malaria risk in them, and performed the following two analyses. In the first analysis, malaria incidence was analyzed in the two house types of only the three villages that encompassed the areas that had a preponderance of houses of good construction (Figure 2); here too, the malaria risk in the poorly constructed houses was significantly higher than in houses of good construction type (Table 1, Analysis I). In the second analysis, malaria incidence rates were examined in each of 14 randomly selected poorly constructed houses in this area located 10–15 meters from each other, and for comparison, in the 14 houses of good construction located closest to each of the poorly constructed houses. The malaria risk was found to be significantly greater in these 14 poorly constructed houses than in their closest neighboring houses of good construction (Table 1, Analysis II). Both these findings indicate that the low malaria risk in the houses of good construction was linked to the house itself and was not likely to have been associated with a particular environmental factor(s) prevalent in the general area.

To examine if the malaria risk in either house type was contingent upon it being located close to a house of the other type, i.e., if persons living in well-constructed houses might benefit from the proximity of poorly constructed houses, which attract mosquitoes and divert them from well-constructed houses, or vice versa, we analyzed the malaria risk in 14 houses with good construction that were located amid a cluster (3–4) of other houses with good construction, having no poorly constructed house within a distance of at least 15 meters of it (Table 1, Analysis III). The malaria risk in these well-constructed houses was not significantly greater than that in the houses with good construction, which were in proximity to a poorly constructed house (Table 1, Analysis II), or than that in their closest neighboring house with good construction (Table 1, Analysis III), suggesting that the ma-
Figure 3. Photographs of houses of A, poor and B, good construction type in the study area.
Malaria risk in the two house types in relation to their distance from a source of water*  

<table>
<thead>
<tr>
<th>Distance from water (m)</th>
<th>Malaria (%) incidence rates (no. of houses)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Good</td>
</tr>
<tr>
<td>0–100</td>
<td>41.5 (47)</td>
</tr>
<tr>
<td>101–200</td>
<td>36.1 (42)</td>
</tr>
<tr>
<td>201–400</td>
<td>68.5 (38)</td>
</tr>
<tr>
<td>&gt;400</td>
<td>62.0 (34)</td>
</tr>
</tbody>
</table>

* Spearman correlation coefficient $r = 0.14, P = 0.0676$ for good houses and $r = -0.31, P = 0.0001$ for poor houses.

There was no significant association between malaria risk to inhabitants and the distances between their houses and the forest edge ($r = -0.09, P = 0.2292$ for houses of the poor construction type and $r = -0.12, P = 0.1431$ for houses of the good construction type).

Estimated impact of risk factor-based interventions. Based on the risk factors identified above, we simulated two types of interventions that would achieve a reduction of the malaria incidence in this population and estimate their potential impact on the incidence of disease. One of these simulated interventions was the imposition of a buffer zone of 200 meters around sources of water, from which poorly constructed houses were excluded. This entailed the simulated removal of 89 poorly constructed houses and their relocation outside the buffer zone (Figure 2 and Table 3). To estimate the impact of this projected change on the malaria incidence in the area, we applied the average malaria incidence rate of poorly built houses located outside the buffer zone to the 89 relocated houses. Based on this intervention, the expected reduction in the malaria incidence was 21% in the whole population and 43.4% in the simulated relocated population (Table 3). The second intervention involved structural improvements to all poorly constructed houses located within 200 meters of a source of water to upgrade them to the standards of those of the good construction type, which entailed projected changes to 89 houses (Table 3). To estimate its impact, we applied the average incidence rate of the inhabitants of the well-built houses within the buffer zone on the residents of the newly improved houses and estimated the new incidence rate. This yielded a 36% reduction of malaria in the whole population and a 75.9% reduction in the population whose houses were improved (Table 3).

The assumption underlying these estimations was that the differences in malaria risk between the residents of the two types of houses were attributable to the construction type of the house rather than to other behavioral and socioeconomic factors pertaining to these individuals. We justify this on the basis of our finding of significantly higher numbers of in-
door-resting mosquitoes in poorly constructed houses, and that the increased risk in being near a source of water applied to residents of poorly built houses, but not to those of well built ones. Both of these observations suggest that underlying the high risk was a higher human-mosquito contact within the poorly built houses, implying that construction type itself, rather than the movement patterns of their residents, was a risk determinant.

Cost implications of interventions. The cost implications of improving house construction types to reduce malaria were examined using general economic principles and mathematical techniques. The approach taken was to estimate the period of time in which the Government’s investment in house construction would be offset by savings to the Government on malaria prevention costs as a result of the malaria infections that would have been prevented by this intervention. The mathematical methods used in these estimations are given in the Appendix.

The cost of malaria prevention was estimated as follows. The total expenditure of the National Malaria Control Program and the Provincial Ministries of Health on malaria control in 1994 was deduced from the Annual Health Bulletin (Ministry of Health, Colombo, Sri Lanka, 1994, unpublished data) and official records of the Ministry of Health and the malaria control program to be approximately 600 million Sri Lankan Rupees (SLR) (US $12 million). This estimate incorporates into this estimate at the rate of decrease of 25% in the second year, 15% in the third year, 10% in the fourth year, and none in subsequent years. We were guided in these assumptions by actual data from a trial of impregnated bed nets that we have performed recently in this region of the country (unpublished data).

These estimates yield a period of 7.2 years in which the cost of improving the construction of the 89 houses would be recovered by net savings on malaria control costs. Using the method described above and in the Appendix, we have also derived solutions for when the assumptions were varied i.e., levels of effectiveness of the malaria control operations of 50% and 75%, and situations in which the impact of reducing the reservoir on transmission was either nil, or was 25% in each of the second and third years, 10% in the fourth year, and none thereafter. The different solutions for each of the assumed set of conditions are given in Table 4.
DISCUSSION

This study confirmed our previous finding that poorly constructed houses impose a significantly higher malaria risk on their inhabitants compared with better built houses. The present study, which was conducted in the same general region as the previous one, but in a different population and over a different period of time, revealed a 2.5-fold greater risk in poorly constructed houses compared with well built ones. We considered the possibility that factors other than house construction type may have contributed to the differences in malaria risk, the behavior of the people, and their habits and occupations to name a few, which are linked to socioeconomic standards and therefore may have been reflected in their house types. As an example, if occupants of houses with poor rather than good construction were engaged in outdoor agriculture at peak biting times of the mosquito, the risk would have been linked to differences in exposure outside the house. If this was the case, it could be argued that house construction type was a mere marker of other actual risk determinants. This is unlikely because in our previous study entomologic investigations revealed significantly higher densities of mosquitoes resting within poorly built houses where the malaria risk was greater than in the well built ones, a feature that would implicitly lead to higher human-mosquito contact rates and an increased risk of contracting malaria within them. In addition, it is conceivable that the features of a poorly built house, such as the lack of windows and doors that could be shut, and wide open spaces between walls and the roof, could make these houses more amenable to mosquito entry. The poorly lit and cooler environment within, which would be more conducive to mosquito resting than the environment within well built houses, would make house construction type itself a potential risk determinant. The possibility should also be considered that the use of preventive health measures such as impregnated bed nets and mosquito coils could have been different in the two types of households; our census information revealed that bed nets were not being used by this population. Thus, while it is possible that other factors may have contributed to the increased malaria risk in poorly constructed houses, our data suggests that the construction type of the house was, in itself, a risk determinant.

We also examined other risk factors of an ecologic nature, and found that the location of a house in relation to a source of water was yet another significant risk factor for malaria in this population, with such sources being potential breeding places of the mosquito vector of malaria. Although there was a significant negative correlation between the distance of houses from a source of water and the malaria risk to their residents when all houses were combined, it was only in the poorly constructed houses that the risk was significant and negative, i.e., the closer a poorly constructed house was located to a source of water, the greater the malaria risk to its inhabitants. Mosquito densities are expected to be higher in the vicinity of breeding places and to lead to high human-vector contact rates, which is the likely basis of the greater malaria risk to inhabitants of poorly constructed houses located nearby. Strangely though, this relationship was not seen in the well built houses, living in which seemed to transcend the risk imposed by being near a source of water. Furthermore, there was in these houses of good construction a tendency for the malaria risk to decrease rather than increase the nearer the house was located to water. This relationship being of borderline significance may not warrant further discussion, although it is conceivable that other overriding factors may come into operation in these better built houses when they are located near a source of water. Whatever the underlying reasons, the differences in the malaria risk patterns in the two types of houses in relation to the distance from water strengthens the argument even further that house construction type must be risk determinant by itself.

The finding of an association between malaria risk and the location of a house in relation to a source of water has implications for irrigation schemes and agriculture-based developmental projects in malaria endemic regions, both of which entail the manipulation of waterways in which malaria vectors breed; such projects are invariably linked to new human settlements close to water (Wickramarachchi MS, 1993, unpublished data). The finding that the higher risk of malaria imposed by being near a source of water can be overcome by a better house construction type and possibly associated higher standards of living is encouraging because such projects are expected to eventually increase incomes and improve living standards of settlers. Our findings also imply that the initial malaria hazard for settlers in such schemes could be significantly reduced by investing in better housing.

We have also examined the impact on malaria transmission and the cost implications of two feasible risk factor-based interventions. One was the imposition of a buffer zone of 200 meters around water bodies, from which houses of poor construction alone would be excluded, and the other was the potential structural improvement of poorly built houses located within this buffer zone. We have shown that these procedures could be expected to lead to a reduction of the malaria incidence in the entire population by 21% and 36%, respectively, and in the high-risk group (residents of poorly built houses within the buffer zone) by 43% and 76%, respectively. The estimates of reduction of malaria incidence in residents of poorly constructed houses have been based only on simple assumptions, such as changing the location or the construction type of houses. If the impact on transmission of a reduction in the reservoir is taken into account, the degree of reduction of malaria that is estimated to ensue will be considerable.

The cost of constructing a house equivalent in structure to those identified here as low-risk houses has been estimated at 42,500 SLR ($850 US). We have estimated the worth of this investment in purely economic terms by setting it off against malaria control costs incurred by the Government. The cost of malaria to the health services of Sri Lanka, and indeed of most endemic countries, is largely the cost of prevention. Almost 60% of the 600 million SLR ($12 million US) spent on malaria control in Sri Lanka in 1994 was used for the purchase of insecticides, and much of the remainder on case detection and treatment to reduce the reservoir, with all this entailing the maintenance of a massive infrastructure for health care delivery. It is for these reasons that the cost of preventing malaria rather than the cost in-
curtained by a breakthrough case of malaria was used as the basis of these estimations. The approach used here to calculate the cost of prevention was based on total malaria control expenditure by the Government; the alternative would have been to estimate and sum the costs of prevention at an individual or household level, for example, the cost of spraying a house with insecticides, the cost of blood films, etc., as has been done previously. The disadvantage of our approach is that it ignores such aspects as the way in which the cost of prevention relates to the load of disease that has to be prevented and, to this extent, our estimates have to be viewed in an abstract way. Its advantage is that it takes into account all the overhead costs of maintaining the infrastructure of a preventive health program of this nature. Our economic estimations are built on the assumption that a lower incidence of malaria will lead to reduced costs in the national prevention program; this is substantiated by the fact that savings will accrue from reduced spraying of houses on the revised strategy of selective house spraying, reduced diagnosis and treatment costs, and reduced tertiary patient care costs. We modeled the worth of a Government’s intervention rather than a community investment on better housing because the cost of preventive health program for diseases of the poor traditionally have and probably always will be borne largely by the Government in developing countries such as Sri Lanka, which have strong social welfare policies.

In determining the cost implications of this intervention, we obtained solutions for several alternative situations such as different levels of effectiveness of the malaria control program and different impacts of reducing the reservoir on transmission. Assuming that the most reasonable of these situations were that the effectiveness of the malaria control program was 66%, the reduction in the reservoir would lead to a curtailment of transmission by 25% in the second year, 15% in the third year, 10% in the fourth year, and none thereafter, and assuming a discount rate of 10%, the period in which the Government’s expenditure on housing will be offset by savings on malaria control costs is about 7.2 years. Beyond 7.2 years, the improvement of house type could be expected to bring a return on the Government’s investment by saving on malaria control costs or the equivalent thereof. This is probably a conservative estimate of the cost effectiveness of this intervention because community costs of malaria, which could be considerable, have been completely left out of our calculations. Moreover, the other health and social gains of improving house type are likely to extend well beyond the effects of preventing malaria, but have not been addressed here.

The real impact of relocating or renovating poorly built houses cannot, however, be known from the simulations performed on this observational study, and they would have to be evaluated in field trials of the proposed interventions. Similarly, the economic analysis presented here, which although based on reasonable assumptions, is hypothetical, and would need to be proven by actual practice. The study, however, apart from identifying risk determinants for malaria, demonstrates how risk factor analyses of this nature could be valuable in formulating disease control interventions, and illustrates how they could form the basis for a more equitable distribution of health care resources. For example, with a large proportion of the malaria control budget currently being spent on insecticides for house spraying, the findings presented here suggest it may be possible, owing to the 2.5 times greater malaria risk in poorly built houses, to restrict house spraying to the poorly constructed houses without appreciably reducing their impact on transmission. Such a decision could, as seen in this instance, halve malaria control costs, and lead to other gains such as possibly even delaying the emergence of resistance to insecticides. The global malaria control strategy recommends reducing reliance on insecticides; the finding presented here suggest that house construction type could be a useful measure for stratifying the spraying program in Sri Lanka.

Even though microepidemiologic findings are often considered to be relevant only to particular situations in which they were studied, the risk factors identified here and their implications are likely to have general application to endemic malaria in Sri Lanka as a whole because the disease is endemic in the dry zone of the country, in which a more or less uniform set of ecologic considerations govern its transmission.

Acknowledgments: We thank Dr. T. Godal and Dr. D. Evans for useful discussions, Wasantha Udaya Kumara and G. Jayasundera for technical assistance, Thilani Lanerolle for secretarial assistance, and the support of our colleagues at the Malaria Research Unit of the Faculty of Medicine, Colombo and the Malaria Research Station at Kataragama.

Financial support: This investigation received financial support from the UNDP/World Bank/WHO Special Program for Research and Training in Tropical Diseases (TDR). R. Carter is a member of the external staff of the Medical Research Council, United Kingdom.

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REFERENCES


4. Mendis C, Gamage-Mendis AC, De Zoysa A, Abhayawar-
APPENDIX

**Estimation of the cost of preventing malaria in the future.** Let \( q_i \) be the discount rate (annual rate of change that is expected due to inflation) for year \( i \).

Assume that \( q_1 = 0 \), and \( q_i = 0.10 \) for \( i = 2, \ldots, n \).

The cost of preventing a single case of malaria in year \( i \) can be summarized as,

\[
x_i = x_1(1 + q)^{i-1}.
\]

**Assets invested in house construction.** Let \( z_i \) be the current value of assets invested in converting houses of the poor type to the good type in year \( i \).

Cost of converting a poorly built house to that of a good one = 42,500 Sri Lankan Rupees (SLR) (US$ 850)

The cost of converting 89 houses = 42,500 \times 89 = 3,782,500 SLR.

Therefore, \( z_1 = 3,782,500 \)

Assuming a discount rate of 10%, \( q_1 = 0.0 \) and \( q_i = 0.10 \) for \( i = 2, \ldots, n \).

The future values of the cost of house construction \( (z_i) \) is given by

\[
z_i = z_1(1 + q)^{i-1}
\]

**Estimation of the decrease of malaria incidence due to reduction in the reservoir.** Let \( p_i \) be the reduction in malaria incidence due to reduction in the reservoir of infection.

Assume that

\[
p_1 = 0.0
\]

\[
p_2 = 0.25 = 25\% \text{ reduction in malaria incidence in the second year}
\]

\[
p_3 = 0.15
\]

\[
p_4 = 0.10
\]

\[
p_5 = \ldots = p_n = 0.00
\]

**Malaria cases prevented by improving house construction.** The number of malaria cases prevented in year \( i \), \( y_i \), is given by

For year 1, \( y_1 = 377 \) (the number of malaria cases prevented as presented in Table 3, adjusted for a period of 1 year)

For year 2, \( y_2 = [377 + 0.25(377)] = y_1(1 + p_2) \)

For year 3, \( y_3 = y_2(1 + p_3) \)

For year 4, \( y_4 = y_3(1 + p_4) \)

For year 5, \( y_5 = y_4(1 + p_5) = y_4 \) (as \( p_5 = 0.00 \)).

For year \( n \), \( y_n = y_{n-1}(1 + P_n) = y_n \)

The above amount can be summarized as

\[
Y_i = \sum [Y_{(i-1)}(1 + P_i)]
\]

**Return on investment.** The total amount saved in year \( i \), \( t_i \), is given by multiplying (1) and (2)

\[
t_i = x_i Y_i
\]

Number of years to offset investment of the intervention, \( z = i \) when \( k_i = 0 \), where \( k_i \) is the amount to be offset at the beginning of the year \( i \) is given by

\[
z = i, \text{ when } k_i = 0
\]

\[
k_1 = z_1 - t_1 = 3,782,500 - t_1
\]

\[
k_2 = k_1 + (0.1)z_1 - t_2
\]

\[
k_3 = k_2 + (0.1)z_2 - t_3
\]

\[
k_4 = k_3 + (0.1)z_3 - t_4
\]

\[
\vdots
\]

\[
k_n = k_{n-1} + (0.1)z_{n-1} - t_n.
\]