RESEARCH
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68

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Cover photo shows a small tank in Sri Lanka.

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Contents

Abbreviations, Acronyms and Sinhala Terminology

AMC – Antimalaria Campaign

API – Annual Parasite Index

DSD – Divisional Secretary Division

GIS – Geographical Information System

GND – Grama Niladhari Division

GPS – Global Positioning System

IWMI – International Water Management Institute

LUPPD – Land Use Policy Planning Department

RMO – Regional Malaria Officer

RS – Remote Sensing

Chena cultivation – Slash-and-burn cultivation

Ganja – Cannabis

Wewa – Tank

Summary

Malaria in Sri Lanka is unstable and epidemic, with large spatial and temporal differences in transmission dynamics. The disease is of great public-health significance and, hence, identification of underlying risk factors is important to target the limited resources for most cost-effective control of the disease. Health-seeking behavior in Sri Lanka is primarily in government-based facilities, with malaria-incidence rates reported in a systematic manner. Recently, the International Water Management Institute launched a project of malaria risk mapping in Sri Lanka to investigate whether this tool could be utilized for epidemic forecasting. We present the first results of the study for the Uda Walawe region in southern Sri Lanka. Data on aggregate malaria-incidence rates, land- and water-use patterns, socioeconomic features and malaria-control interventions were collected and put into a geographical information system. Malaria cases were mapped at the smallest administrative level, namely the Grama Niladhari Division. Relative risks for different variables were calculated employing multivariate analyses. Areas of high malaria risk were characterized by a) more than average rainfall, b) a large forest coverage, c) *chena* (slash-and-burn) cultivation, d) the presence of abandoned tanks, and e) a poor socioeconomic status. The risk of malaria in irrigated rice cultivation areas was lower than in other areas. People performing irrigated agriculture generally have higher socioeconomic, nutritional and health indicators, live in better-constructed houses, and use preventive measures more frequently, and these might explain their lower malaria risk. However, ecological idiosyncrasies in malaria vector density or species composition might also account for this difference. Our findings call for malaria-control strategies that are readily adapted to different ecological and epidemiological settings. Malaria risk maps are a convenient tool for discussion with control personnel and for assisting them in targeted and cost-effective interventions.

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Introduction

Malaria is an important public-health problem in Sri Lanka. In 2000, there were 210,000 reported cases among a total population of 19 million (Fernando 2001). The transmission of malaria in Sri Lanka is unstable and, hence, its incidence greatly fluctuates from one year to another and exhibits important variations within a year. Large epidemic outbreaks can occur; the latest was observed in 1987 with 920,000 reported cases among 16.1 million inhabitants at that time. The number of malaria cases due to *Plasmodium falciparum*, the most pathogenic of the four human malaria parasites, is increasing: in 1999, *P. falciparum* accounted for 26 percent of malaria cases compared to only 11 percent in 1985 (Ministry of Health 2000). This, together with the spread of antimalarial drug resistance (Handunnetti et al. 1996), has further aggravated the malaria problem in Sri Lanka, even though the incidence has not reached epidemic levels since 1987. The principal vector involved in malaria transmission in Sri Lanka is *Anopheles culicifacies*. Several other species have also been reported to be locally involved in transmission (for a recent review see Konradsen et al. 2000a). In Sri Lanka *An. culicifacies* prefers breeding in pools, riverbeds and slow-flowing streams, but breeding can also occur in tank beds and drainage pools. It has recently been speculated that habitat preference might be more diverse than was previously assumed (for a review see Konradsen et al. 2000a).

In general, high transmission is often related to either excessive rainfall, creating additional vector-breeding places, or exceptionally low rainfall causing the pooling of rivers and streams to form major breeding sites. In such instances, malaria can become epidemic, and several devastating epidemics have occurred after the failure of the southwest monsoon (Konradsen et al. 2000a). Although, in general, malaria transmission is related to rainfall patterns, it can vary greatly in time and space. Research in the dry zone of Sri Lanka has suggested that the linkage between malaria and rainfall might have weakened and that it has been complicated due to ecological transformations (van der Hoek et al. 1997). Apart from rainfall and river-flow velocities, several other malaria risk factors have been identified in Sri Lanka, e.g., utilization of control measures (van der Hoek et al. 1998), age and gender (Mendis et al. 1990; van der Hoek et al. 1998), human migration (Klinkenberg 2001a), as well as type and location of housing (Gamage-Mendis et al. 1991; Gunawardena et al. 1998; van der Hoek et al. 1998). Because of spatial and temporal variation of malaria transmission it is important to better understand and quantify the underlying risk factors, so that control efforts can be targeted to the high-risk areas. For spatial risk analysis and predictive forecasting, geographical information systems (GIS) and remote sensing (RS) have become increasingly important. For example, several studies have been carried out with an attempt to predict the distribution and abundance of disease vectors (for a comprehensive overview see Hay et al. 2000).

GIS and Malaria

In Sri Lanka, GIS tools have already been applied to investigate the spatial relation between malaria risk and distance from breeding sites (Gunawardena et al. 1998; van der Hoek et al. 1998). Other studies have focused on the identification of key malaria risk factors at the microscale (household level). However, no attempt has been made to date to explain, on a larger scale, the existing malaria patterns by linking disease-incidence data with environmental, population, socioeconomic and entomological features on a GIS platform. Some studies of this type have been done in other epidemiological settings of Asia, Africa and the Americas. For example, a recent study in China found that malaria was mainly influenced by the physical environment, the presence of efficient vector species and mobile populations along the area bordering neighboring countries (Hu et al. 1998). Another study in Thailand, utilizing spatial analysis to explain malaria and dengue patterns, revealed that the two diseases exhibited great seasonal variations, but were associated with a provincial economic status. Consequently, both diseases required different demands on the use of control resources (Indaratna et al. 1998). In Gujarat, India, application of GIS techniques revealed the importance of a high water table, soil types, irrigated agriculture and water quality (Srivastava et al. 1999). Interestingly, a previous study carried out by the International Water Management Institute (IWMI) in Gujarat found no statistically significant correlation between malaria-incidence rates and water-related environmental features. The importance of high-quality data for subsequent spatial analyses, for the use of GIS for visualization of parameters, and for input in statistical analyses was emphasized (Mutuwatte et al. 1997). In The Gambia (Thomson et al. 1996, 1999) and Kenya (Hay et al. 1998a), the application of RS-derived NDVI[1] data for malaria forecasting has been investigated; the NDVI, lagged by one month, showed significant correlation with malaria cases. In Africa, a large initiative was launched, the MARA/ARMA collaboration, set up to map malaria risk in Africa and to establish a continental database of the spatial distribution of malaria to provide relevant information for rational and targeted implementation of malaria control. Based on meteorological data, a malaria distribution model was created to show the regions that are suitable, stable or unsuitable for malaria (Craig et al. 1999; Hay and Lennon 1999; Hay et al. 1998b; MARA/ARMA 1999; de Savigny 2000). These maps showed a striking resemblance to historical malaria-case data maps and the model is now being refined for different regions.

Data on environmental determinants of malaria risk can be obtained with relative ease for subsequent processing with GIS and RS tools. On the other hand, malaria incidence rates that are necessary for the definition of risk factors or the validation of predictive models, still have to be collected on the ground at the periphery. The biggest problem in Africa, some parts of Asia and the Americas, is the lack of reliable data on malaria incidence or prevalence on a regular basis. This can be partially explained by extensive self-treatment of patients, often with antimalarial drugs purchased at local shops or kiosks, increasing use of private health facilities that are not reporting to government-based health information systems, and a high

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[1] NDVI = normalized difference vegetation index = NIR-R/NIR+R (NIR = near infrared; R = red).

proportion of cases receiving presumptive treatment without any laboratory diagnosis. For example, in Pakistan it was found that 80 percent of the people obtain treatment outside the government health facilities (Donnelly et al. 1997). A study in Kenya reported that only 18 percent of a study population sought treatment at a rural health center or hospital while 60 percent used self-medication and 22 percent sought no treatment at all (Ruebush et al. 1995). For a recent review on self-medication of malaria, with particular focus on sub-Saharan Africa, we refer to McCombie (2002). These observations seriously limit the validation of GIS-based risk maps with data from the routine health information system in many countries.

The Sri Lankan Situation

The situation in Sri Lanka is more favorable as several studies have indicated that government-based health facilities are still the preferred diagnosis and treatment centers and people almost exclusively use Western-type drug-based treatment and prefer diagnosis confirmation by blood film (Konradsen et al. 1997, 2000a, b). Although a study in the Moneragala district in the eastern part of the country showed that the percentage of people seeking treatment in private facilities was as high as 46 percent, self-medication for malaria was relatively low and 70 percent of treatment was based on microscopic confirmation of infection (Abeysekera et al. 1997). In Huruluwewa, in the northern part of the dry zone, the majority of the people seek treatment in government-based health facilities (Konradsen et al. 2000b). At present, therefore, malaria incidence data as recorded routinely in Sri Lanka's government facilities give a good representation of the actual malaria situation. Consequently, linking malaria incidence rates with demographic, environmental and socio-economic factors is feasible. Because of the unstable and epidemic character of malaria in Sri Lanka it is not only necessary to identify the high-risk areas, but also to develop an early warning system for impending epidemics (van der Hoek et al. 1997). Such predictive forecasting can help refine the spatial and temporal application of control measures, and reduce both the societal and governmental costs due to malaria. Therefore, IWMI embarked on an ambitious project to generate malaria risk maps for the whole island of Sri Lanka, and to investigate the possibilities for the development of an early warning system.

In a first step, the Uda Walawe region, located in IWMI's Ruhuna Benchmark Basin in southern Sri Lanka, was selected for piloting this approach. The main purpose is to determine and quantify associations between malaria incidence rates and predominant land- and water-use patterns, meteorological features, and socio-economic status of different communities.

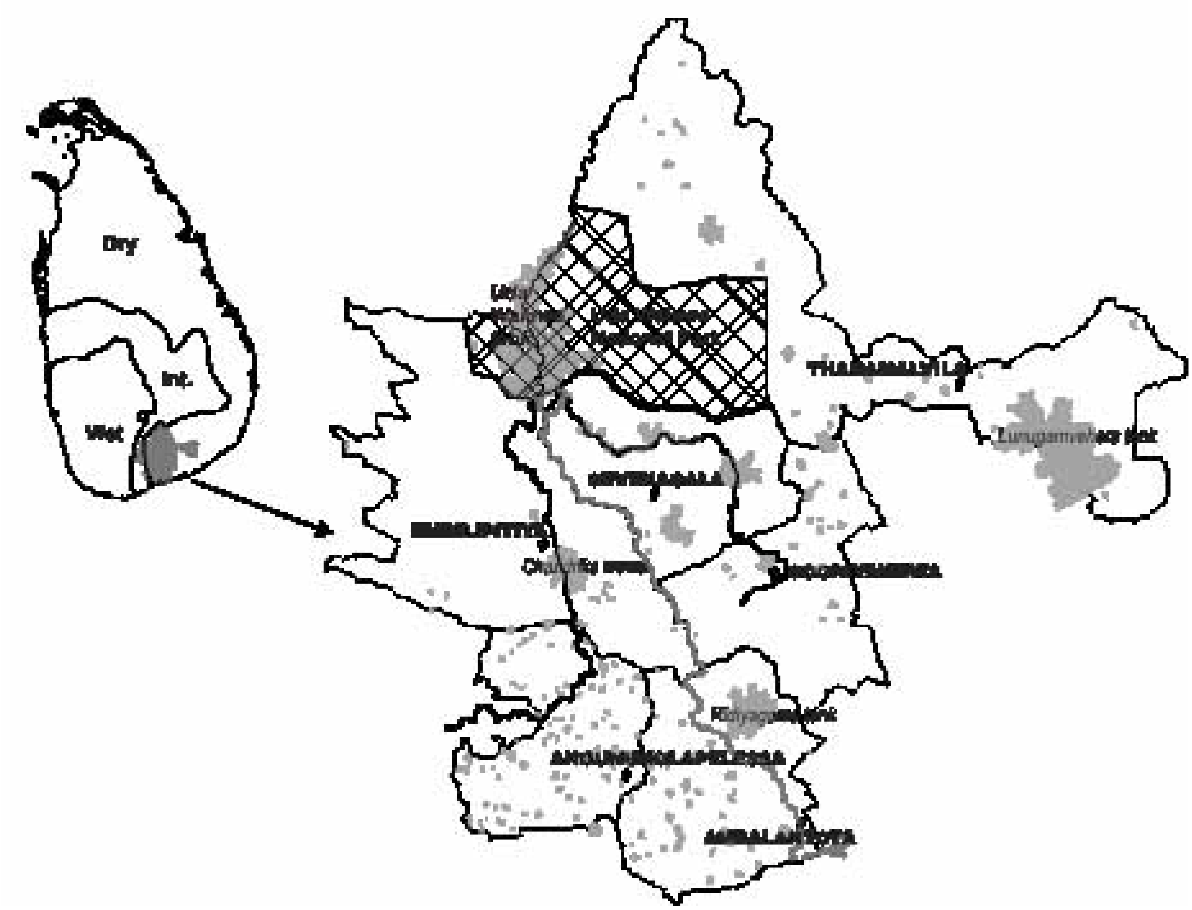
The present report documents the key malaria risk factors for the Uda Walawe region, where monthly malaria incidence data were available over a 10-year period. An additional objective of the study was to discuss with local malaria control personnel and health workers the role that risk mapping could play in the planning of malaria control activities in their area. The results of these workshops were reported previously (Klinkenberg 2001a, b).

Methodology

Site Description

The Uda Walawe region is situated in the dry climatic zone of Sri Lanka, which receives less than 2,000 mm of rain per annum (figure 1). The climate is characterized by nearly constant year-round temperatures ranging between 26 °C and 28 °C. There is a north-south rainfall gradient; annual rainfall around the northern Uda Walawe reservoir is approximately 1,500 mm, decreasing to 1,000 mm in the southern coastal areas (SL/JICA 1993). About 70 percent of rainfall is received in *maha* (wet agricultural season from September to March), mainly related to the northeast monsoon, whereas the remaining 30 percent occurs in *yala* (dry agricultural season from April to August).

FIGURE 1.
Study area in relation to the three climatic zones of Sri Lanka.
(Int. is intermediate zone)



The study was carried out in six Divisional Secretary Divisions (DSDs) in the Uda Walawe region: Thanamalvila, Sevenagala, Embilipitiya, Sooriyawewa, Angunukolapelessa and Ambalantota. A DSD is an administrative division below the District level (figure 2). Each DSD is subdivided into Grama Niladhari Divisions (GNDs), which as stated earlier are the smallest governmental administrative divisions in Sri Lanka. A Grama Niladhari (village administrative officer) typically oversees 2-3 villages. Larger towns can consist of several GNDs. The six DSDs in the present study belong to three different districts: Ratnapura, Moneragala and Hambantota (figure 2). Until 1996, Sevenagala was part of Thanamalvila. The total land area covered by the six DSDs is 1,820 km^2 and the population of this area is about 375,000. These DSDs together have 196 GNDs. Maps of each DSD with the respective GNDs are given in appendix A. There are altogether 14 government health facilities located in the area. Characteristics of each DSD are shown in table 1.

FIGURE 2.
Administrative boundaries in Sri Lanka.

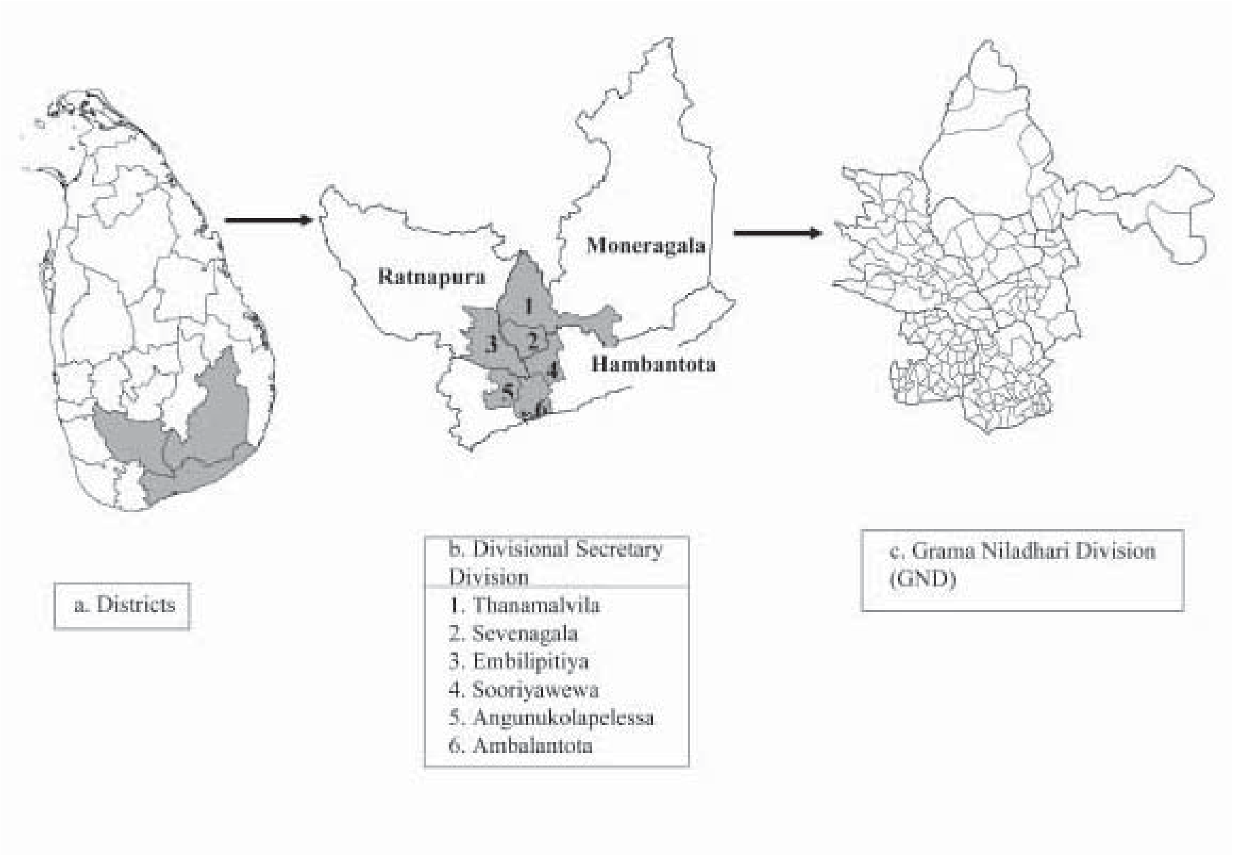


TABLE 1.
Characteristics of the different DSDs included in the study.

DSD	Embilipitiya	Angunukolapelessa	Ambalantota	Sooriyawewa	Thanamalvila	Sevenagala	Total
# GND	41	51	55	21	14	14	196
Area (km^2)	397	173	215	186	671	186	1828
Population (year 2000)	140,746	47,153	71,521	42,803	26,173	47,222	375618
Population density (persons/km^2)	354	271	333	230	39 (54)[a]	254	257 (249)[a]*
Annual rainfall (mm)[b]	1,586	1,195	1,042	1,144	1,804	1,375	1358*
Health facilities present	1 BH 2 DH 1 RH 1 CD	1 PU 1 DH 1RH	1 PU 1 CD	1RH	1DH 1 PU	1RH	14

Note: BH = Base Hospital; PU = Peripheral Unit; DH = District Hospital; RH = Rural Hospital; CD = Central Dispensary.

[a] A large part of the Thanamalvila DSD is occupied by the Uda Walawe National Park. If this area is omitted from the calculation, the population density is 54.2 persons/km^2. The Uda Walawe National Park is 296 km^2, and the part located in Thanamalvila is 189 km^2.

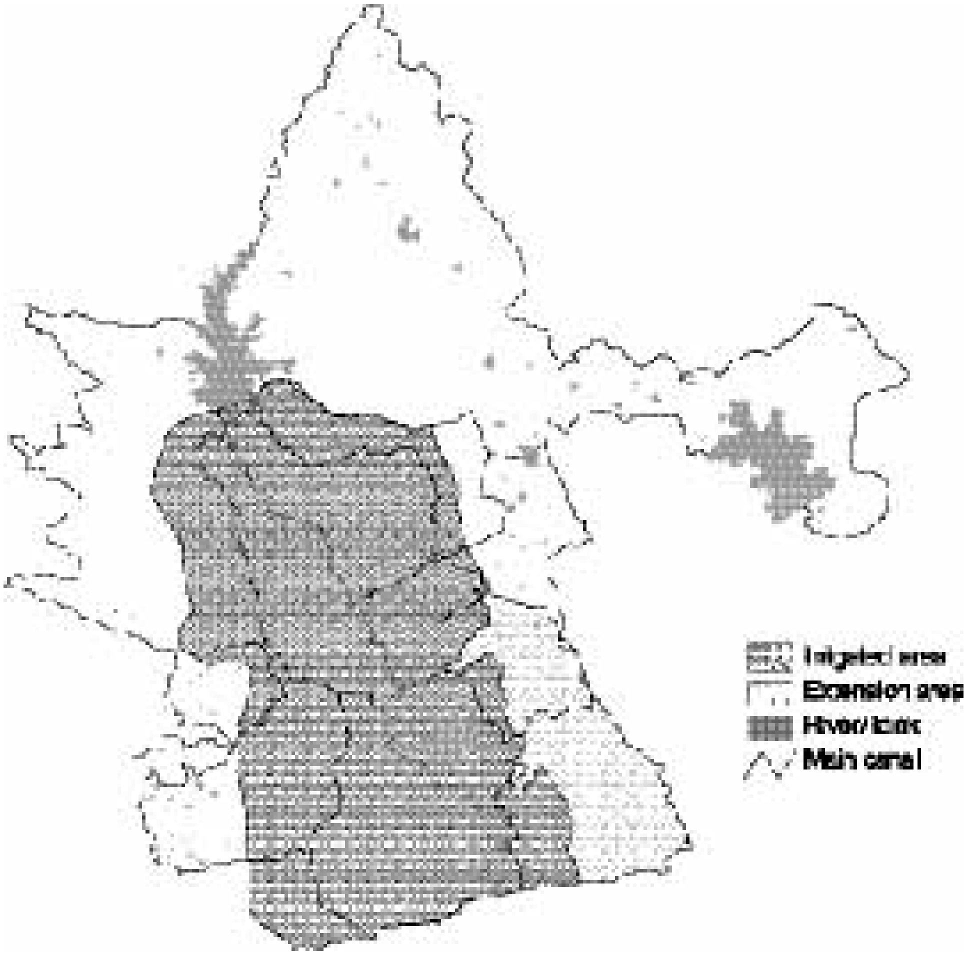
[b] Data are for June 1999 to May 2000.

* Average of the 6 DSDs.

A major irrigation scheme, the Uda Walawe Irrigation and Extension Project (figure 3), was developed in the Walawe river basin from 1967 onwards (SAPI 2000). In 1993, the right bank command area was about 12,000 hectares, irrigating mainly paddy but with expanding areas of banana and other field crops (OFCs), such as vegetables and pulses. The left bank command area was about 5,000 hectares, divided into 2,000 hectares of sugarcane and 3,000 hectares of paddy. Now the Uda Walawe irrigation system has several water reservoirs that are interconnected (in Sri Lanka, reservoirs are usually termed tanks or *wewas*). The main reservoir is the Uda Walawe tank with a capacity of 268 million m^3. The irrigated area is fed through two main canals on the left and right banks of the Walawe river. These canals flow through several smaller tanks that contribute to the project's overall water resources (SAPI 2000). Currently, irrigation development is about to start in the lower part of the left bank extension area (figure 3). Many small tanks with command areas ranging from 10 to 70 hectares are located in this extension area; some of them will be upgraded and the area will be developed as a small tank cascade system, in contrast to the already developed area, which is based on a few large tanks.

The main crops cultivated within the irrigation system are paddy, banana and OFCs (SAPI 2000). The area around Sevenagala is cultivated mainly with sugarcane. Home gardens planted with coconut, jak and fruit trees are characteristic for this area. The main activities outside the Uda Walawe irrigation scheme are *chena* (slash-and-burn) cultivation, mainly in the northeastern part of the area (Thanamalvila) and in the areas bordering the irrigation scheme. Within Thanamalvila there are also several remote, difficult-to-access areas where illegal *ganja* (cannabis) cultivation takes place. The northern part of Embilipitiya is more mountainous with small tea plantations, and small rice paddies in the valleys. Gem mining takes place in some areas (e.g., around the Ridiyagama tank and in areas in the Embilipitya DSD) and the gem pits are abandoned after usage.

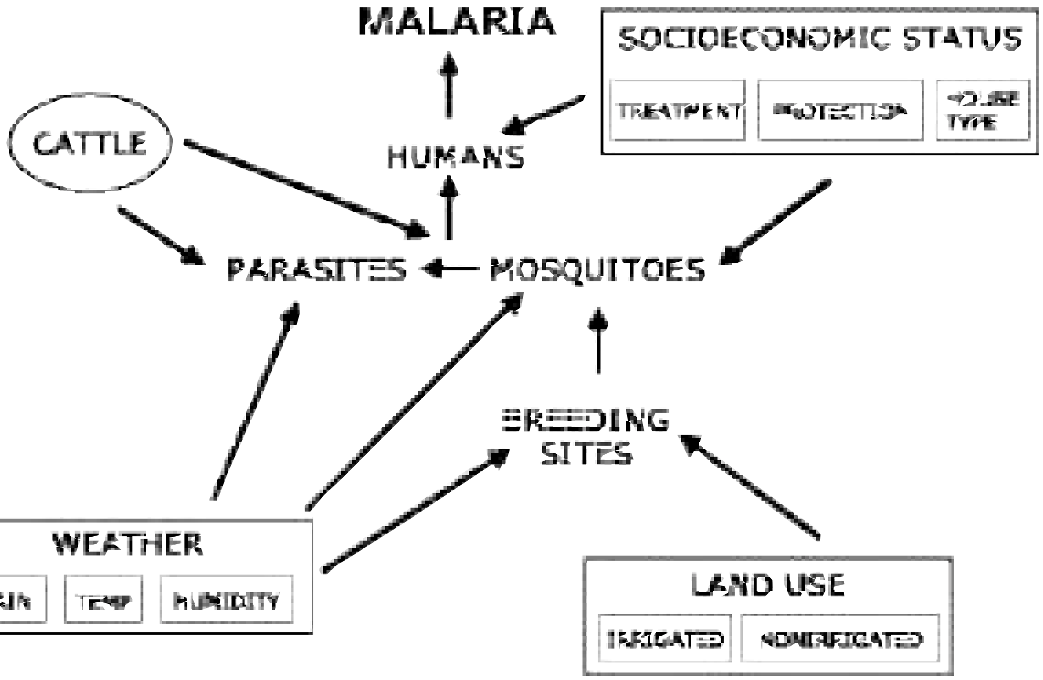
FIGURE 3.
Location of the Uda Walawe irrigation and extension project within the study area.



Data Collection and Processing

Different factors influence the malaria transmission cycle (figure 4). To identify the risk factors for malaria in the Uda Walawe region, data on the different factors were collected from maps, reports and databases from different government departments, and from previous IWMI projects or literature. The main data available were those on malaria incidence, land- and water-use patterns, socioeconomic features and on malaria-control interventions. For details on collected data, e.g., level, source and period, see appendix B.

FIGURE 4.
Influence of different parameters on the malaria-transmission cycle.



Malaria-Incidence Data

Malaria-incidence data, disaggregated by village, were collected from all the government-based health facilities located within the six DSDs (figure 5) from January 1991 to August 2000. These data refer to laboratory-confirmed cases of malaria. Mixed infections of *P. falciparum* and *P. vivax* were reported as *P. falciparum*. Data were not available for all years in all hospitals. The nonavailability of data is largely explained by the absence of microscopists or field assistants in the hospitals (appendix C). In addition, data were collected from three health facilities located just outside the six DSDs because these attracted patients from within the study area, according to key informants. Malaria data from private clinics were not available, as these facilities do not systematically record these data. On the other hand, data from mobile clinics were included when available.

To calculate the malaria-incidence rate, GND-level population data were collected from the respective DSD offices. Population data were not available for certain years and for these years they were estimated by linear interpolation between previous and subsequent years. Abeysekera et al. (1997) have argued that the GND level is the most appropriate division for malaria-incidence analysis in Sri Lanka and this was followed in the present study. They considered it most appropriate and better than the village level since it is based on the number of families rather than on the extent of land;

FIGURE 5.
Location of hospitals within the study area from which malaria data were collected.

Note: BH = Base Hospital; DH = Districts Hospital; PU = Peripheral Unit; RH = Rural Hospital; CD = Central Dispensary; MTC = Malaria Treatment Centre.

defined administratively rater than by usage, which a village tends to be; and it is an accepted and standard division, which is being used by other sectors such as the Land Use and Statistics Departments.

As data on malaria in the government-based health facilities were recorded on the basis of village names, each village had to be assigned to its appropriate GND. Only about 50 percent of the villages from where malaria cases were reported in the hospitals (herein called malaria-villages) could be found on the official list of names of villages with their respective GNDs obtained from the Department of Census & Statistics (1992/1993 village-level data per DSD). This was probably due to several factors:

1. People use different names for the same village.
2. Some people would report the name of their GND if asked for the name of their village.
3. Translation of village names from Sinhala to English can be difficult, as village names are often quite similar.

To overcome these problems, the locations of all villages were determined with a hand-held global positioning system (GPS) receiver (type GARMIN GPS40). GPS procedures and consideration are described in appendix E.

Malaria incidence was calculated for each GND as the number of cases per 1,000 inhabitants, both per month and per annum. Sometimes, villages and, especially, larger towns, consisted of more than one GND. In these cases, the GNDs were merged and the malaria incidence was calculated for the larger area. For example, Ambalantota North and South were merged as hospital records only noted Ambalantota and did not differentiate between the two GNDs. See appendix D for a complete list of the GNDs that were merged for computation of malaria-incidence rates.

Basic Geographic Features, and Land- and Water-Use

To obtain basic geographic features (e.g., road network and streams), and land- and water-use patterns for the study area, 1:50,000 scale maps were obtained from the Survey Department of Sri Lanka, with permission from the Ministry of Defence. The DSD boundary layers were obtained from the Survey Department of Sri Lanka in the ARCINFO format. This layer was used as the standard outline for each DSD and, where necessary, maps from other departments were adjusted to this DSD outline. GND boundaries were digitized from maps provided by each Divisional Secretariat. These GND boundary maps were not geo-referenced; therefore, they were adapted to the geo-referenced DSD outline obtained from the Survey Department. All villages were assigned to their respective GNDs by plotting the villages on the map and overlaying the GND boundary layers. Villages for which the GND was known were used to cross-check the GND boundary maps, as these originated from non-geo-referenced maps drawn by the DSD officials.

Land-use data were collected from the Survey Department and the Land Use Policy Planning Division (LUPPD). To reflect changes in land use that had occurred between 1990 and 2000, the maps of both departments were used. Appendix E indicates in detail what considerations were taken into account for the land-use patterns.

As *An. culicifacies*, the chief malaria vector in Sri Lanka, prefers to breed in pools in riverbeds and slow-moving streams, the length of streams per square kilometer for each GND was included in the analyses. Proximity of the location of houses to a river or a stream had been identified previously as a risk factor for malaria (Gunawardena et al. 1998; van der Hoek et al. 1998). Therefore, buffer layers of 250 m were created along rivers and streams, which is a straightforward GIS technique. The percentage of buffer area to the total area in a GND was used as a covariate representing proximity to rivers/streams. A distinction was made between natural streams and irrigation canals and these were included as two separate covariates.

Socioeconomic Features and Malaria-Control Data

Socioeconomic data were obtained from a report published by the Department of Census and Statistics in 1993 and from a questionnaire survey carried out by IWMI in 2000 (Unpublished data of Intizar Hussain of IWMI). The report of the Department of Census and Statistics contained data for the whole study area of the GND, including the number of houses, the number of families, the number of families receiving food subsidies, the number of landless families and the number of families whose houses were supplied with electricity.

IWMI's questionnaire survey was conducted among 261 households in 42 different GNDs located within the study area. Because the sampling fraction of households for each GND was very low (in 86% of the GND less than 5% of households, and in 50% of the GND less than 1% of households), an estimate of the questionnaire variables at the GND level would be unreliable. Therefore, the questionnaire data were only used to investigate for differences at the DSD level. The primary information derived from the questionnaire survey used for our study consisted of the use of protective measures against mosquitoes, as well as farm incomes. Farm income was estimated on the basis of income and expenditure data, a negative balance indicating that a particular household was in debt.

Data on indoor residual insecticide-spraying activities for malaria control in the area were obtained from the Anti-Malaria Campaign (AMC). For the purpose of our analysis, each GND was categorized as sprayed or non-sprayed. The limited data did not allow for a more refined analysis.

Meteorological Data

Data on rainfall and soil moisture were available on a monthly basis at the GND level for the period of June 1999 to May 2000 from a previous IWMI project with the Meteorological Department of Sri Lanka. Based on point data from 142 rainfall stations, rainfall grids were interpolated on monthly bases covering the whole country using the *kriging* technique (Mason et al. 1994). For this study, monthly data on rainfall for each GND were extracted from the country-wide maps using GIS techniques. Data on soil moisture, both average value and maximum value per GND, were obtained from satellite images derived from the National Oceanic and Atmospheric Administration (NOAA). Details of soil moisture calculations are given in appendix F.

Data Handling

In our GIS platform, all data were entered in decimal degrees with the Kandawela datum, following the system of the Survey Department maps. Data in other coordinate systems were converted to the longitude-latitude coordinate system with the Kandawela datum, using ILWIS and ERDAS IMAGINE software.

Except for the meteorological covariates, all other covariates were only available on an annual basis. Consequently, annual malaria-incidence rates were used as outcome measures for spatial analyses. For the year 2000, data were available only for the period January to August and, therefore, this year was excluded from further analyses. For all covariates except land use, data were available only for one year. Land-use data were included in the annual analysis according to appendix E. We assumed that the data on malaria cases were independent between the years and that the geographic variation in the covariates did not change substantially between the years. Therefore, the same covariate dataset was related to each year’s malaria-incidence data.

The meteorological data, e.g., on rainfall and soil moisture were available on a monthly basis and for these covariates a separate monthly analysis was carried out to investigate if there was a correlation between monthly malaria-incidence rates and rainfall or soil moisture. Both covariates were also lagged by 1-2 months. Apart from the separate monthly analysis, meteorological data were also represented in the annual analysis by annual rainfall per GND and maximum soil-moisture value per GND.

The digitizing of the maps needed for the present study was sometimes difficult because different departments used different coordinate systems and slightly different administrative boundary outlines. Moreover, not all maps were correctly geo-referenced. Therefore, one standard was chosen with one DSD and GND boundary outline to which all other maps were transformed. Also, problems occurred within maps of the same system, as adjoining map sheets were updated in different years and therefore did not always fit at the borders. This was solved by manually adjusting the layers at boundaries to make them fit at the borders. As discrepancies were not very large, ground truthing missions were not undertaken.

Statistical Analysis

Malaria-incidence rates and incidence-rate ratios were calculated for “high” and “low” values of each covariate. The values of each covariate measured on a continuous scale were coded as either 1 or 0 with the median value as cutoff point to represent a high or low value of that covariate. The median value was used in the absence of a better justification for placing the cutoff point at any other value. Value 1 was assigned to the category that was expected to pose the highest risk for malaria. For example, a GND with more land area covered by paddy was assigned the value 1 while a GND with less paddy was assigned the value 0, based on the expectation that more paddy in a GND would be associated with a higher malaria risk in that GND. Appendix G shows the descriptive statistics, i.e., the mean, median, maximum and minimum values, and the number of valid cases for the variables considered in the study. Confidence intervals (CI) for the incidence-rate ratios were calculated according to Rothman 1986.

A logistic regression analysis was carried out, with the SPSS software package (version 8.0), to investigate the association between the outcome variable—the malaria score—and the categorized covariates at the GND level. The outcome variable was derived by recoding case count data as 1 or 0 based on a cutoff value of annual parasite incidence (API). Three cutoff values were investigated to represent low, moderate and high-risk scenarios. In Sri Lanka, the AMC considers malaria to be under control if API is lower than 10 cases per 1,000 inhabitants per annum. This value was adopted for the low-risk scenario. An API of 30 was utilized as the cutoff value for the moderate-risk scenario and an API of 100 for the high-risk scenario. In the logistic regression analysis the malaria score was coded as 1 for values above the cutoff value and 0 for values below the cutoff value. Logistic regression is of the form:

$$\text{Prob (event) / Prob (no event)} = e^{B0 + B1\ X1 + B2\ X2 + \ldots\ldots + Bp\ Xp}.$$

where, Exp (Bi) is the factor by which the odds change when the i^{th} covariate changes by one unit. For the covariates as categorized in this analysis, Exp (B_i) is the odds ratio of category coded as 1 relative to category coded as 0. The outcome is shown in appendix J.

Malaria Risk Map

Disease incidence. Figure 6a shows the total number of malaria cases reported to all the hospitals within the six DSDs for each year during the period 1991-1999. The absolute number of cases decreased in 1993 and 1994 but showed a steady increase after 1996. By far the largest number of cases were recorded at hospitals in Thanamalvila and Embilipitiya (figure 6b). The records of the hospitals showed that the majority of patients were from the DSD in which the health facility was located (table 2).

FIGURE 6a.

Total number of malaria cases reported to all the hospitals in the 6 DSDs in the period 1991-1999.

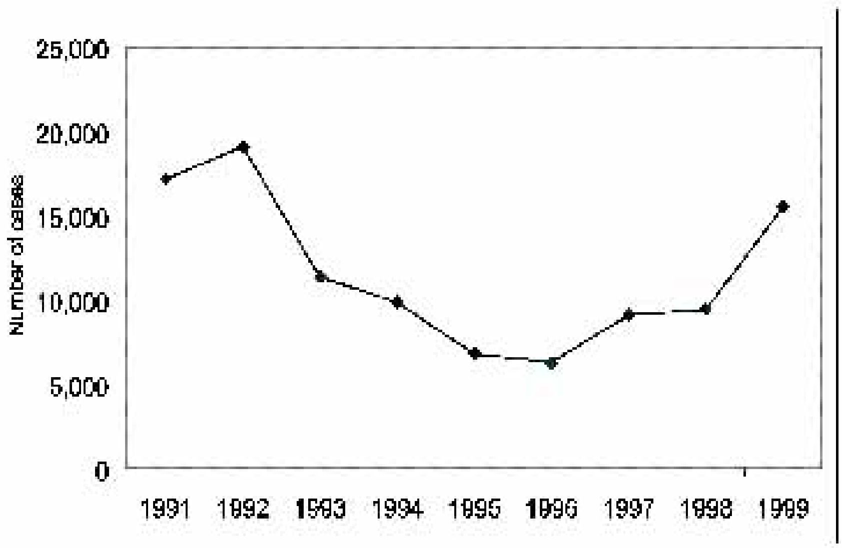


FIGURE 6b.

Contribution of different DSDs to the total number of malaria cases in the study area in the period 1991-1999.

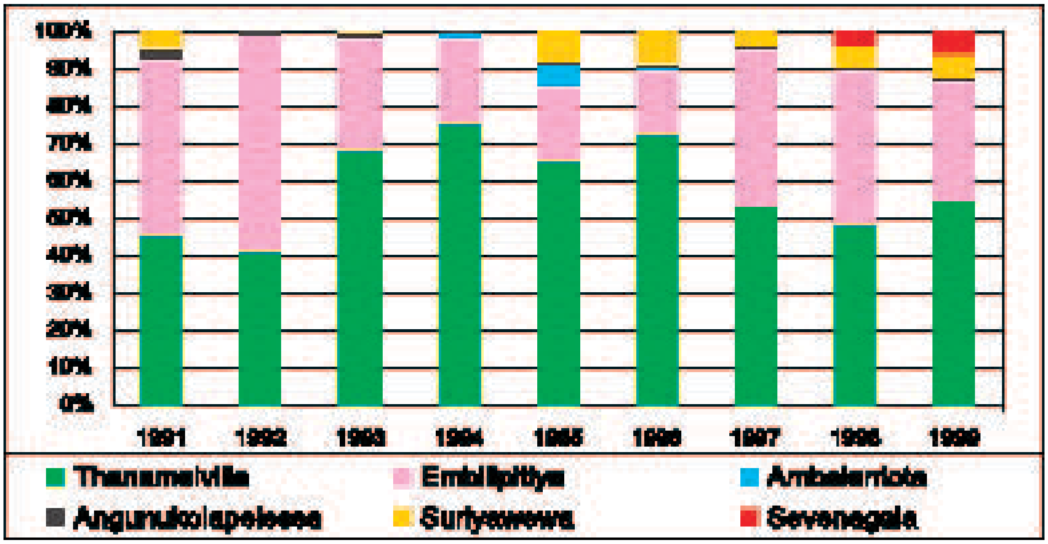


TABLE 2.
Percentage of malaria patients visiting health facilities from within or outside the DSD in which the hospital is located.

Government Health Facility	From within DSD (%)	From outside DSD (%)
Ambalantota, PU	97.7	2.3
Angunukolapelessa, PU 7	5.6	24.4
Chandrika Wewa, DH	61.4	38.6
Embilipitiya, BH	98.0	2.0
Hakuruwela, RH	100.0	0.0
Hambagamuwa, PU	99.8	0.2
Kariyamaditta, DH	97.4	2.6
Mullediyawala, CD	100.0	0.0
Pallebedda, DH	100.0	0.0
Ridiyagama, CD	91.9	8.1
Sevenagala, RH	100.0	0.0
Suriyawewa, RH	91.2	8.8
Thanamalvila, DH	85.7	14.3
Uda Walawe, RH	94.8	5.2

Note: PU = Peripheral Unit; DH = District Hospital; BH = Base Hospital; CD = Central Dispensary; RH = Rural Hospital. Names given in italics are those of hospitals where a substantial number of patients come from outside the DSDs to which the hospitals belong.

Mobile clinics were mostly used in the Thanamalvila and Uda Walawe areas, which can be considered remote areas. Annual malaria incidence in the study area showed a consistent pattern over the 10-year period commencing 1991 (figure 7). Within each year and over the years, Thanamalvila had the highest malaria incidence, ranging from 50 to 500 cases per 1,000 inhabitants per annum. Malaria incidence in the rest of the study area was considerably lower with annual rates of less than 50 cases per 1,000 inhabitants, except for some high incidence rates in the GNDs of Embilipitiya along the Ratnapura road. However, even these GNDs showed a decrease in incidence after 1993, with the exception of the Maduwanwela GND. The time series showed a slight overall decrease in malaria incidence over the period 1991–1999. In the low-incidence area, the decrease was, on average, from 6–50 to 1–5 cases per 1,000 inhabitants per annum and the risk decreased from moderate to low according to the classification employed by the AMC. In the Thanamalvila area the incidence decreased from more than 500 cases per 1,000 inhabitants per annum to 200–500 cases per 1,000 inhabitants per annum, but even with this lower incidence it can still be considered a high-risk area.

FIGURE 7.
Annual malaria incidence at GN level for the Uda Walawe area.

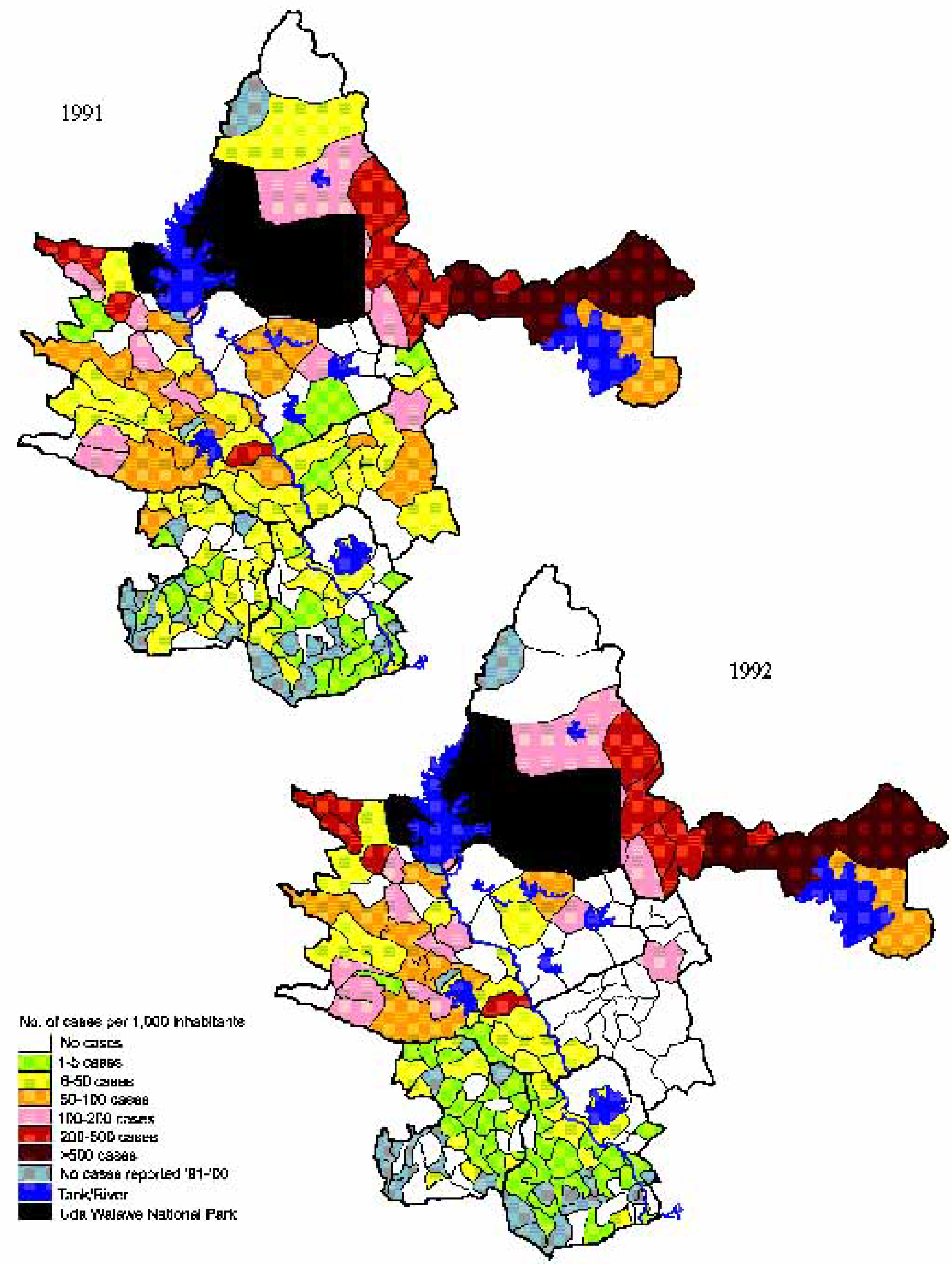


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FIGURE 7.
(Continued)

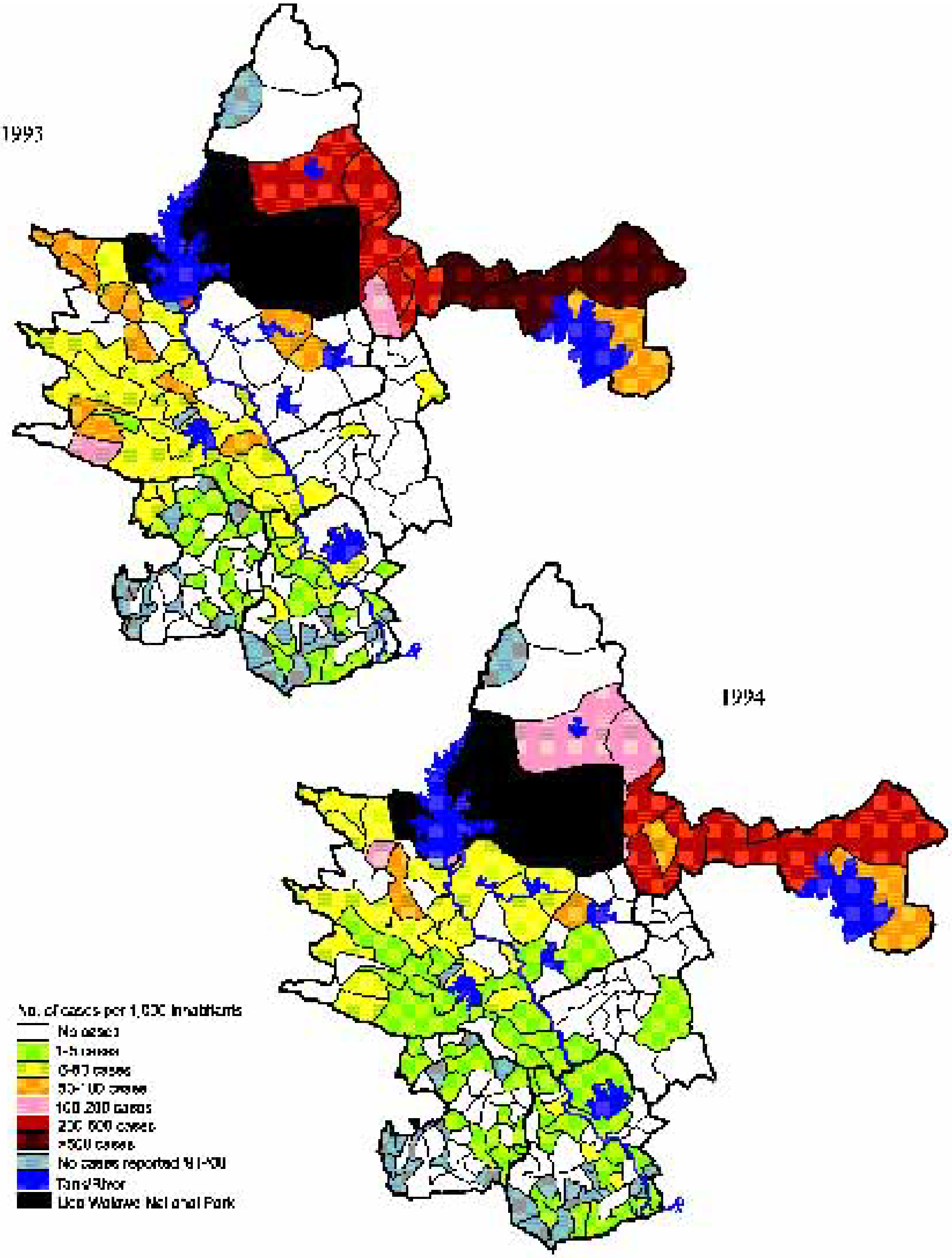

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FIGURE 7.
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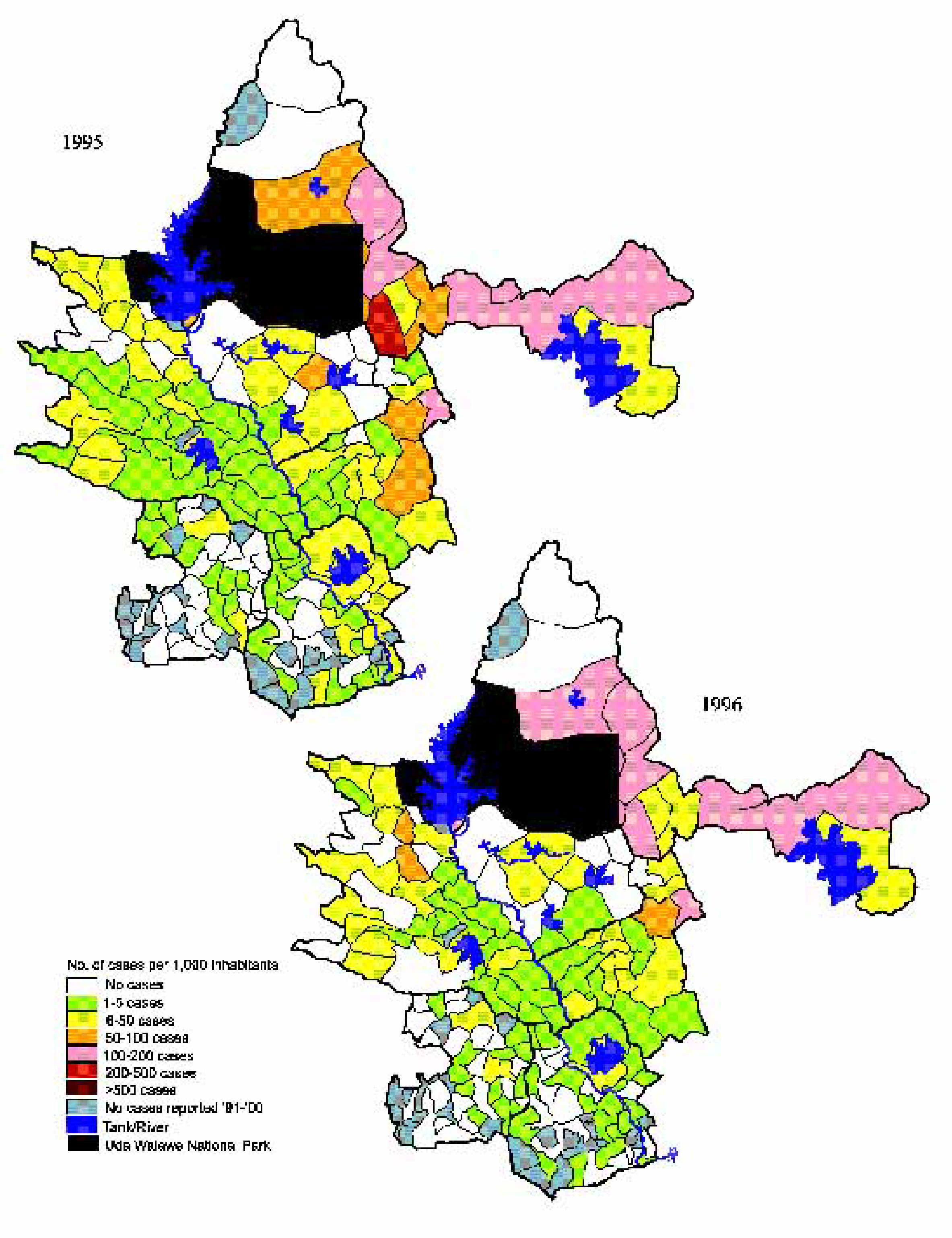

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FIGURE 7.
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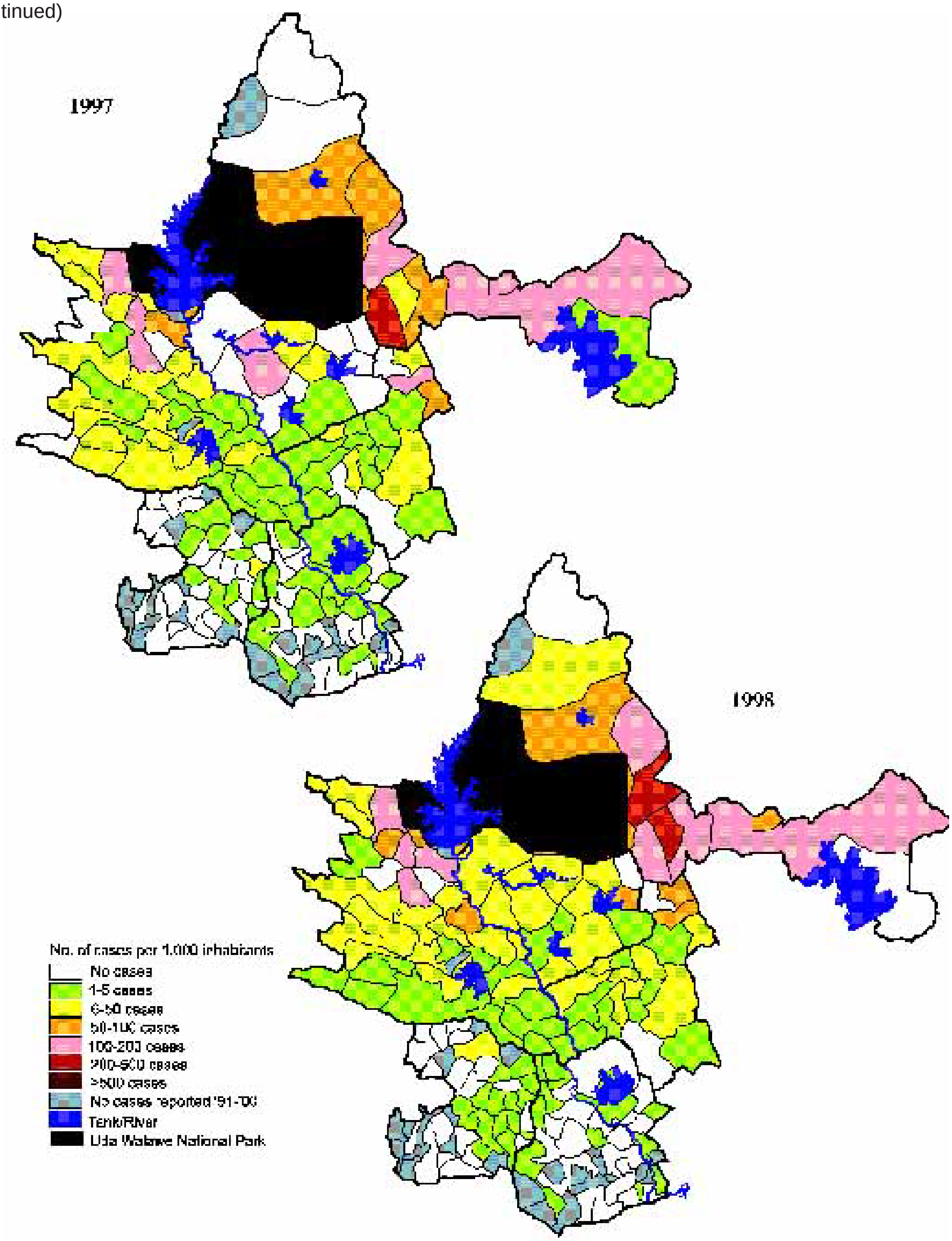

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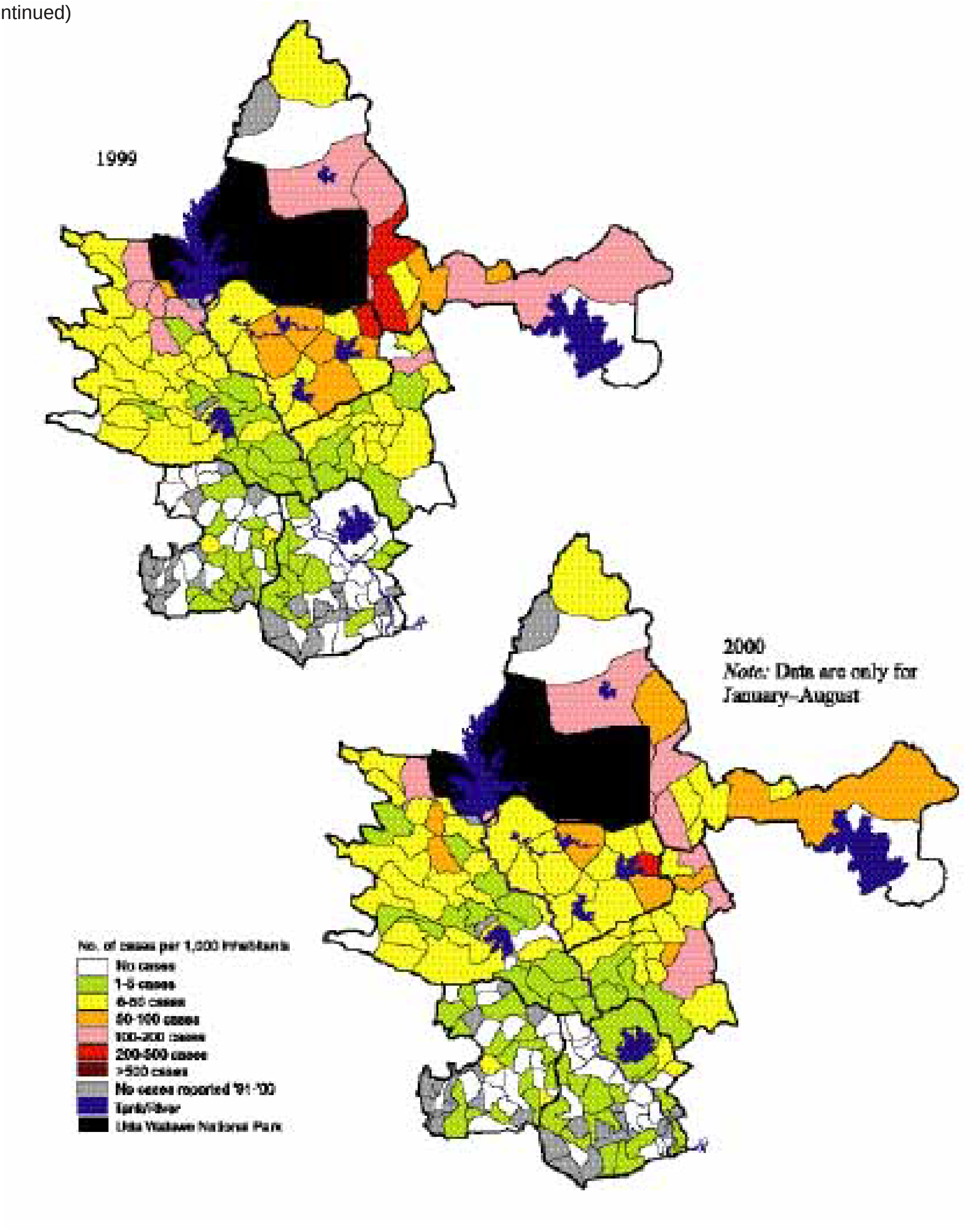
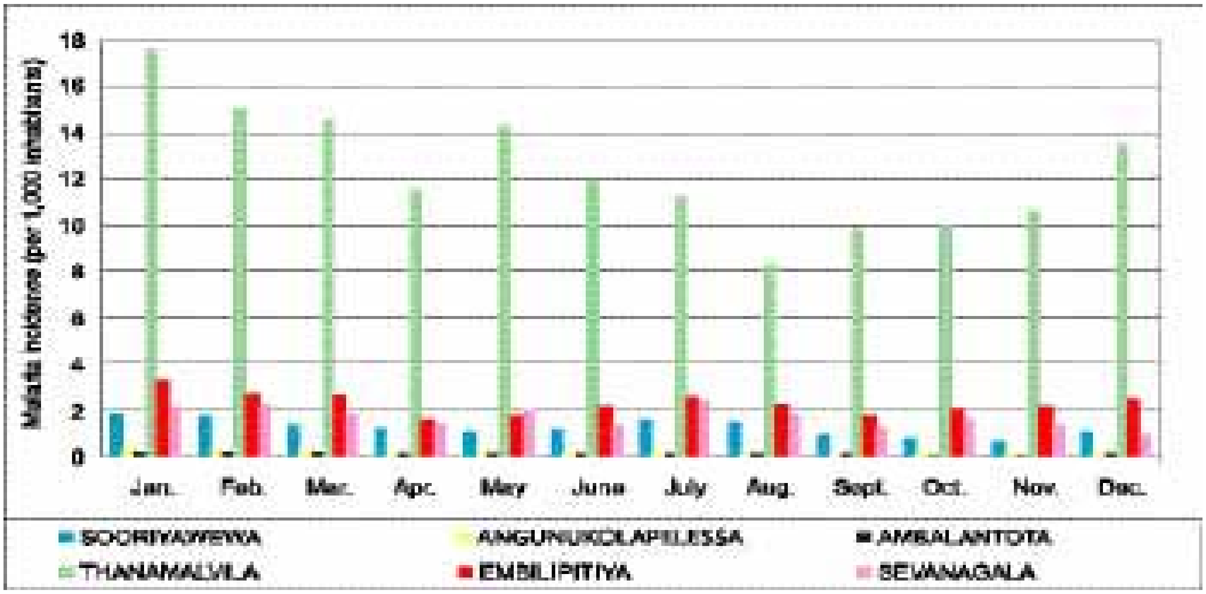
FIGURE 7.
(Continued)



Seasonal trends in malaria. The monthly malaria-incidence data in the Uda Walawe area (example shown in appendix H) did not reveal a clear seasonal pattern. In Thanamalvila (see location in figure 1) GNDs had higher and lower incidences without a clear pattern. For the other DSDs malaria incidence was low in general and did not seem to have a distinct seasonal pattern either. However, the monthly malaria incidence for each DSD over the period 1991–2000 (figure 8) suggests that malaria incidence was higher in January and February with a smaller peak in May and June, which is the typical seasonal pattern in Sri Lanka (Konradsen et al. 2000a).

FIGURE 8.
Average malaria incidence per month per DSD over the period 1991-2000.



Note: For the year 2000 there were only data till August 2000.

Risk-Factor Analysis

Land use. There were clear differences in land use between the different DSDs (table 3a). Thanamalvila had less paddy cultivation than in the other DSDs. Chena cultivation is known to be extensively practiced in Tanamalvila, but the percentage of land cover used for chena cultivation was only 9 percent according to the available land-use data. The actual area under chena cultivation is likely to be higher than reported here because parts of scrub and forest-land are also used for chena cultivation (Land Use Policy Planning Department, personal communication 2001). Table 3b shows the number of irrigation schemes present in the different DSDs and the percentage of the schemes that were abandoned. Thanamalvila had a very high percentage of abandoned schemes, which is also visible from the distribution of working and abandoned tanks in the study area (figure 9). A field trip in the

Thanamalvila area in March 2001 revealed that most of the tanks that were classified as abandoned were, in fact, still used by groups of farmers or some individuals (Klinkenberg 2001a). Most tanks contained some water year-round although in the dry season (June), small tanks dried up or contained only 10 percent of their full capacity (unpublished field-trip data, June 2001).

TABLE 3a.

Land-use distribution per DSD. Numbers are percentages of land area within a DSD.

DSD	Scrub[b]	Chena	Forest	Home garden	Paddy	Other crops	Tanks-working	Tanks-abandoned	Rock-sand	Lagoon-marsh	Settlement
Embilipitiya[a]	5	40	8	25	15	3	4	0	<1	<1	nr
Ambalantota	17	<1	<1	10	55	7	5	<1	<1	5	nr
Sooriyawewa	9	39	4	25	18	<1	2	3	<1	0	nr
Thanamalvila	40	9	22	12	5	1	4	4	<1	2	<1
Sevenagala	5	15	<1	24	14	35	5	2	<1	<1	<1
Angunukolapelessa	11	0	<1	27	41	19	1	<1	<1	<1	<1

Note: nr = not recorded as classification category

[a] Data are for 1985; part of chena area is now developed into paddy or other plantations (personal communication, LUPPD Ratnapura 2001)

[b] Including grassland and barren land.

Source: Land Use Policy Planning Division maps: Sooriyawewa 1995; Ambalantota 1996; Thanamalvila 1998; Angunukolapelessa 1996; Survey Department map: Embilipitiya field revision 1984.

TABLE 3b.

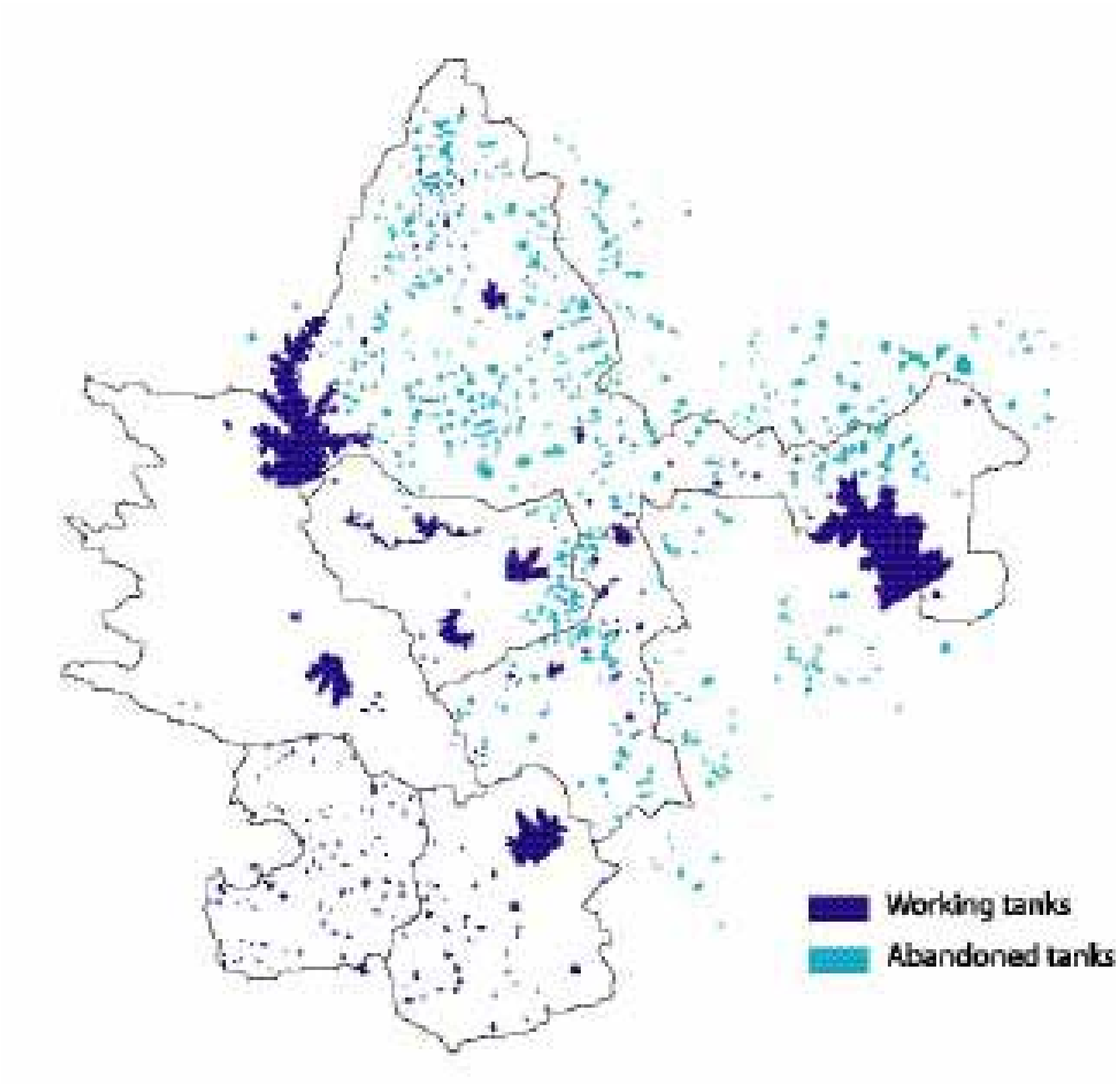
Total number of irrigation schemes and percentage of schemes abandoned in the different DSDs.

DSD	No. of schemes	Schemes abandoned (%)
Embilipitiya	37	11
Sooriyawewa	3	0
Ambalantota	24	0
Angunukolapelessa	27	15
Thanamalvila-Sevenagala*	38	58

*Data were not reported separately for the two DSDs.

Source: Data book for village irrigation schemes in Sri Lanka (2000; field data 1998-1999), Department of Agrarian Services, Sri Lanka.

FIGURE 9.
Location of working and abandoned tanks in the Uda Walawe area.
(after maps of the Survey Department.)



Socioeconomic indicators. The socioeconomic indicators (tables 4a, b) showed that, in general, the Uda Walawe region is a poor area with more than 60 percent of the families receiving some kind of food subsidies. Farm income was lowest in the Thanamalvila DSD, where 75 percent of the surveyed farmers had an annual income of Rs 10,000 (approximately US$110) or less; which is about one-fifth of the income of the farmers in the other DSDs. Also the total area cultivated per farmer was smaller in the Thanamalvila area than in other areas.

TABLE 4a.
Socioeconomic data per DSD.

DSD	No. of families	No. of houses	Families receiving food subsidies (%)	Families having electricity (%)	Landless families (%)	No. of.livestock per family
Sooriyawewa	7,400	7,115	65.9	4.5	5.2	1.3
Angunukolapelessa	9,285	8,995	66.0	11.7	13.3	1.0
Ambalantota	13,617	12,412	59.2	25.3	19.0	1.0
Thanamalvila	4,738	4,645	87.5	5.9	14.3	1.6
Embilipitiya	17,969	17,526	67.7	12.6	6.4	0.6
Sevenagala	7,512	7,341	61.5	4.7	16.2	0.7

Source: Department of Census and Statistics, Sri Lanka, 1993 data.

TABLE 4b.
Statistics of monthly farm and non-farm income and area cultivated per DSD.

		Angunukolapelessa	Ambalantota	Thanamalvila	Embilipitiya
Non-farm income	n	160	25		89
(SLRs)	M	0	750	no data	0
	75%	263		3,000	375
Farm income	n	160	25	36	89
(SLRs)	M	28,169	36,340	2,185	24,833
	75%	56,406	117,631	10,068	64,595
Area cultivated	n	160	25	36	89
(ha)	M	4	5	1.5	3
	75%	5	5	2	4.1

Note: n = No. of households sampled; M = median; 75% = 75 percentile. US$1.00 = Rs 90.

Source: IWMI questionnaire survey, year 2000; villages within Sooriyawewa and Sevenagala DSD were not included in the questionnaire

Data on the usage of bed nets and other malaria-control measures were available only for three of the six DSDs, e.g., Angunukolapelessa, Embilipitiya and Ambalantota. The usage of bed nets reported in these areas was high (60-70%, see table 5). It should be noted that these three DSDs are the areas where malaria incidence rates are generally low (see figure 7).

Malaria Risk Factors

Calculation of the relative risk for the different parameters considered in this study showed that an increased malaria-incidence rate was associated with a) more than median rainfall in a GND; b) more chena cultivation; c) more forest coverage; d) less paddy cultivation in a GND;

e) higher percentage of families receiving food subsidies; and f) higher proportion of area covered by abandoned tanks (table 6 and appendix I). Furthermore, the incidence was higher in areas where indoor residual insecticide spraying by the AMC took place.

TABLE 5.
Mosquito protection measures of the population within the different DSDs.

	DSD	Angunukolapelessa	Ambalantota	Embilipitiya
N		102	31	62
Protection [a]	Never	5.6	2.9	4.4
	Sometimes	24.1	20.6	10.3
	Always	70.4	76.5	85.3
Measure [b]	Bed net	65.7	59.4	71.4
	Coils	33.3	40.6	27
	Other	1	0	1.6

[a] Response to the question “Do you protect yourself from mosquitoes?”.

[b] Response to the question “How do you protect yourself from mosquitoes?”.

Source: IWMI questionnaire; note that for Thanamalvila, Sevenagala and Sooriyawewa DSD no households were included in the questionnaire; n = number of households surveyed; except for sample size (n) all numbers given are the percentages of people who gave that specific answer.

TABLE 6.
Calculation of incidence-rate ratios with 95% confidence intervals (CI) for the different parameters.

	Criteria	n	INC	IRR	95% CI
Land use					
Grass, scrubland and barren land as land cover in a GND	<3%	868	16.6	1.00	
	>3%	725	34.6	2.09	(2.07-2.11)
Forest as land cover in a GND	<1%	1,341	14.8	1.00	
	>1%	252	78.1	5.29	(5.23-5.34)
Paddy as land cover in a GND	<30%	816	36.3	1.00	
	>30%	777	7.5	0.21	(0.20-0.21)
Chena as land cover in a GND	<5%	881	9.4	1.00	
	>5%	712	35.9	3.83	(3.80-3.86)
Abandoned tanks as land cover in a GND	<1%	1,332	16.4	1.00	
	>1%	261	65.0	3.96	(3.92-4.00)
GNDs within 250 m to a natural stream	<25%	810	21.3	1.00	
	>25%	783	27.4	1.29	(1.27-1.30)
Socioeconomic status					
No.of livestock per family in a GND	<1	1,035	20.3	1.00	
	>1	558	36.0	1.77	(1.75-1.80)
Families receiving food subsidies within a GND	<65%	810	15.2	1.00	
	>65%	783	34.8	2.28	(2.26-2.30)
Families having electricity in a GND	>5%	774	18.8	1.00	
	<5%	819	30.6	1.63	(1.61-1.64)
Meteorological data					
Annual rainfall per GND	<1,200 mm	783	5.3	1.00	
	>1,200 mm	810	36.0	6.76	(6.71-6.81)
Malaria control measures					
Spraying activities within a GND	Spraying	414	52.2	1.00	
	No spraying	1,179	10.3	0.20	(0.19-0.20)

Note: n = valid value count; INC = malaria incidence per 1,000 inhabitants per annum; IRR = incidence rate ratio (relative risk). Appendix I shows all covariates.

Although malaria data were available at the village level on a monthly basis for 10 years, most covariates were only available at the GND level and that only for one year. This limited the possibilities for a very detailed risk-factor analysis over time.

The total combination of variables entered in the logistic regression model explained about 40 percent of the variation in malaria incidence at the GND level. Therefore, the variables included in the analysis are insufficient to build a predictive model, as a large part of the variation in malaria- incidence rates remains unexplained. Table 7 and appendix J show the importance of different risk factors based on the logistic regression analysis for three different scenarios: low, moderate, and high risk. Different parameters became more or less important as the scenario changed from low to high risk. Average rainfall of >1,200 mm and >1% forest cover were the most important parameters, being significant risk factors at all levels (low, moderate and high) of risk analyzed. Abandoned tanks became clearly more important in the high-risk scenario, as was the percentage of families receiving food subsidies.

The malaria incidence at the DSD level did not show a significant temporal correlation with rainfall. Analysis of relationships between soil moisture, rainfall data and malaria incidence on a monthly basis showed very weak correlations (Pearson’s correlation coefficient <0.2). A higher-than- median rainfall in a GND was associated with an increased incidence of malaria, but this probably reflected the geographical distribution of the rainfall. Previous research to correlate rainfall with malaria data in the dry zone of Sri Lanka also showed a very weak correlation and it was suggested that ecological transformations have weakened the linkage between malaria and rainfall as it has been reported from the beginning of the twentieth century (van der Hoek et al. 1997).

TABLE 7.
Relative importance of different covariates for malaria risk under different scenarios.

Variable	Low-risk scenario	Moderate-risk scenario	High-risk scenario
>1% forest in a GND	++	+++	++++
<30% paddy in a GND	++	ns	ns
<30% other crops	--	ns	ns
>5% chena	+	++	ns
>1%working tanks	+	++	++
>1% abandoned tanks	ns	++	++++
>25% GNDs within 250m of a natural stream	+++	++	ns
>15% GNDs within 250 m of an irrigation canal	ns	++	ns
>1 livestock per family	-	ns	ns
>65% families receiving food subsidies	ns	ns	++++
>1,200 mm annual rainfall per GND	++	++++++	++++++
No spraying in a GND	----	-----	---------

Note: Low-risk scenario cutoff point annual parasite incidence (API) of 10 cases per 1,000; moderate-risk scenario API of 30; high-risk scenario API of 100, based on results of logistic regression analyses, details in appendix J. ns = not significant.

Discussion

Our study showed a consistent pattern of malaria incidence in the Uda Walawe area over the period 1991–2000 with a highly increased risk for malaria in areas that have a relatively large proportion of land under forest cover and chena cultivation. Irrigated rice-cultivation areas had a generally low incidence of malaria. Other important risk factors for high malaria-incidence rates were the presence of abandoned tanks and a higher-than-median rainfall. The population in the areas with chena cultivation and with many abandoned tanks has a lower socioeconomic status than communities living in irrigated areas. However, the poor socioeconomic status was also an independent risk factor for malaria. Some conclusions and issues arising from the study are discussed below.

GIS-Based Risk Maps

A clear distinction should be made in discussions on risk mapping between case incidence maps, risk maps and predictive models. GIS tools can be used as a first step for the simple mapping of malaria cases; in this way, high- and low-incidence areas can be defined on the basis of a meaningful threshold. Such maps of case incidence can be readily converted into risk maps by assigning high and low risk to different categories of incidence, and this can be displayed, for example, by using different colors A second step is to analyze the existing malaria patterns and correlate them to demographic, environmental, meteorological and socioeconomic covariates to identify risk factors underlying these patterns. In a sequential step, these risk factors could be utilized to build a model for prediction of malaria risk. However, this approach will be successful only if factors that are included have a sufficiently large impact on malaria incidence if they are to be used for prediction. For a predictive model to be of value in the preparation for impending epidemics the risk factors should be measurable several weeks in advance. Thomson et al. (2001) emphasized that alongside weather monitoring and seasonal climate forecasts, epidemiological, social, and environmental factors can also play a role in predicting the timing and severity of malaria epidemics. However, even a simple case incidence map at the local scale is useful in assisting better targeting of malaria-control activities by identifying high-incidence areas.

A larger objective of the malaria risk factor analyses done in this Sri Lankan study is to construct a risk map of malaria for the entire country. One constraint is that, presently at the national level, all data on malaria cases that are recorded in a certain hospital are assigned to the DSD in which the hospital is located and not to the DSD in which the patient is living. Administrative units that have important health facilities could, therefore, show a high malaria incidence while malaria risk in the administrative unit itself is, in fact, low. In the pilot study presented here, which was confined to six DSDs, the actual residence of patients was used in the spatial analysis of malaria incidence and risk. This would not be feasible in a larger national-level study. Currently, the AMC is introducing a new health-information system, which records malaria data at the lowest administrative level, the GNDs. The value of this approach, first suggested by Abeysekera et al. (1997) is supported by the findings of our study. Once implemented, it would be a system with a level of detail that is unique in the developing world and would, eventually, generate data that allow accurate national-level risk mapping.

Reporting of Malaria Cases

Case reporting procedures at government-based health facilities are sufficiently well organized to generate reliable data that can be used for the type of analyses done in this study. However, data on people using self-medication for malaria and those seeking treatment from private health facilities are not captured in the routine health-information system. The values presented are therefore underestimates of the real incidence. It could be argued that the differences in malaria incidence between administrative units could have been caused by differential treatment-seeking behavior. We are confident that this is not the case. Although a study by Abeysekera et al. (1997) reported that 46 percent of the population in a district-wide survey sought treatment at western-type private facilities, the other studies that have been done in Sri Lanka on malaria treatment-seeking behavior consistently report a preference for government-based health facilities for the diagnosis and treatment of malaria (see Konradsen et al. 2000b).

Land Use, Vectors and Malaria

The finding that irrigated areas that have abundant water in reservoirs, canals and rice paddies, have a low risk for malaria seems counterintuitive. Although the major malaria vector for Sri Lanka, *An. culicifacies*, is not a rice-field breeder and the major vector-borne disease associated with irrigated rice in Sri Lanka is Japanese Encephalitis (Amerasinghe 1993), it could still be expected that within an irrigation system conditions are more favorable for vector breeding due to the presence of an extensive canal network, seepage areas of canals, and other permanent water bodies. In contrast to the water-rich irrigated areas, the chena-scrub-forest areas are relatively dry and it can be expected that here malaria is confined to the rainy season, when rain creates temporary breeding places.

Looking at the presence of water bodies (figure 9) it is clear that in the Thanamalvila area a large number of so-called abandoned tanks are present. The statistical analysis also showed an increased malaria risk for areas with these abandoned tanks. A field trip to the area to investigate these abandoned tanks revealed that they were not, in fact, abandoned but were still being used by farmers for crop cultivation. A preliminary larval survey found no breeding of *An. culicifacies* in these tanks but, instead, several possible secondary vectors, i.e., *An. annularis* and *An. vagus*, were found (Klinkenberg et al. 2001a). Anopheline larval ecology was recently described for a number of tanks in north-central Sri Lanka demonstrating that the major malaria vector did not occur frequently but secondary malaria vectors and others involved in malaria transmission did occur in abundance (Amerasinghe et al. 2001). A systematic larval survey of these so-called abandoned tanks that is presently in progress should reveal if there is indeed consistent breeding of possible secondary vectors. If so, additional entomological and epidemiological studies are warranted to investigate if the species found breeding in the tanks indeed play a role in malaria transmission in the area.

At present, there is only scanty entomological data available, so no detailed assessment can be made of mosquito species and densities between the high- and low-risk areas. In general, it is assumed that the major vector for Sri Lanka is *An. culicifacies* and control activities are focused on this vector. However, if secondary vectors turn out to be locally important in transmission this would have important implications for the current control strategies of indoor residual spraying. Secondary vectors such as *An. annularis* and *An. vagus* are primarily outdoor-biting and resting species and, therefore, indoor-residual spraying would be less effective (Amerasinghe et al. 1991; Ramasamy et al. 1992). Interesting to note in this context is that in one village in Thanamalvila a small outbreak of malaria occurred in March 2001 just after the village was sprayed (personal communication. RMO Moneragala, March 2001). One possible explanation for this could be that outdoor-resting, secondary vectors of malaria were not affected by the spraying campaign.

In general, there is no straightforward relationship between irrigated rice cultivation and malaria (Service 1989; Ijumba and Lindsay 2001; van der Hoek et al. 2001; Ijumba et al. 2002a, b). Sharma and Mehrotra (1986) concluded that, in India, rice cultivation has a very weak or no relationship to malaria transmission. In Madagascar, the main vector of malaria is *An. funestus*, which almost exclusively breeds in rice fields (Laventure et al. 1996). In West Africa, the same vector is rarely found in rice fields. However, the main vector of malaria in most of sub-Saharan Africa, *An. gambiae s.l*., has long been associated with rice cultivation (Surtees 1970; Lindsay et al. 1995). Even when local disease vectors breed in rice fields this does not necessarily lead to more human disease. Improved standards of living in irrigated areas could result in less contact with mosquitoes when people live in better houses and make more use of preventive measures. Also, better access to health care and antimalarial drugs, and greater willingness to take sanitary measures can play a role. In Tanzania, a village with rice irrigation had higher numbers of malaria vectors but less-intense malaria transmission than a nearby savanna village (Ijumba 1997). The irrigated village was more affluent, with better nutritional status of children and greater use of bed nets. Studies in different ecological zones in West Africa found high densities of malaria vectors in rice-irrigated areas but the incidence of malaria was lower than outside the irrigated areas (Robert et al. 1992; Teuscher 1998). In contrast, in Burundi, there was a very localized high prevalence of malaria close to irrigated rice fields and flooded areas, and irrigation development led to a stabilization of previously unstable malaria (Coosemans et al. 1984; Coosemans 1985). In Sri Lanka, the Mahaweli Development Project caused a sharp increase in malaria incidence (Goonasekere and Amerasinghe 1988).

The Socioeconomic Dimension

The increased malaria risk in chena-grass-scrub areas and decreased risk in paddy areas could be partly explained by differences in the socioeconomic status between the two areas. The very high malaria incidence recorded in Thanamalvila is coupled with a distinctly lower farm income than in the other DSDs and more people receiving food subsidies. Although we had no access to data on type of houses in the different DSDs it can be assumed that in the areas with a lower socioeconomic status the type of housing construction is poor. Earlier studies in Sri Lanka have revealed that the risk of being infected with malaria was up to 2.5 times greater for people in poorly constructed houses, with thatched roofs and mud walls than for people in better-constructed houses (Gamage-Mendis et al. 1991; Gunawardena et al. 1998; Konradsen et al. 2000a). The importance of the socioeconomic status in malaria transmission in Sri Lanka was also stressed by other researchers (Pinikahana 1992; van der Hoek et al. 1998). The very low malaria incidence in the irrigated areas could be related to the fact that farmers in the irrigated area can be expected to be richer and, therefore, have more resources to construct better houses, buy bed nets and other antimosquito devices, and seek early diagnosis and treatment. In different areas of Africa, the improved socioeconomic status resulting in buying bed nets and antimalarial drugs has been suggested as an explanation for low-malaria prevalence in irrigated areas (Lindsay et al. 1991; Boudin et al. 1992; Ijumba and Lindsay 2001). Chena cultivation was considered a risk factor for malaria in earlier studies, because during the cultivation period farmers and their families stay in temporary *cadjan* (thatched coconut-palm leaves) huts which are open and, therefore, easier for mosquitoes to enter and rest in. Farmers also often sleep outside their huts due to the hot climate and are, therefore, more exposed to mosquito bites and more susceptible to malaria (Gunawardena 1998). The chenas are often located in normally uninhabited areas deep in the jungle where no treatment and control facilities are available. If people become infected with malaria they go back to their hometown and also contribute in this way to the transmission of malaria (Gunawardena 1998). Another aspect that increases the risk in chena cultivation areas is that after burning forest for chena cultivation, the resting places of mosquitoes are greatly reduced, which push mosquitoes to rest in houses (Konradsen et al. 2000a). Discussions with local malaria-control personnel (Klinkenberg et al. 2001a) revealed that the human migration to the chena areas of Thanamalvila from other DSDs like Ambalantota and Embilipitya was an important risk factor for importing cases to these areas.

Bed Nets and Indoor Residual Insecticide Spraying

In areas where the IWMI questionnaire survey was carried out, more than 70 percent of the households always used protective measures, primarily bed nets. The area in which the questionnaire survey was carried out was unfortunately only the low-incidence area and, therefore, the high bed-net use in this area suggests that there are probably high densities of nuisance-biting mosquitoes, but not necessarily vectors of malaria that make people use the nets. Further entomological investigations in the high- and low-risk areas should indicate if differences in vector densities or species composition could play a role in differences found in malaria risk. It should be noted that the reported bed-net use is very high compared to other areas. Konradsen et al. (1997) found only 23 percent of bed-net use in surveyed households in the northern dry zone of Sri Lanka and reported this to be a high coverage.

It seems surprising that areas that were sprayed by the AMC with residual insecticides had a higher risk for malaria than areas that were not sprayed. However, this could probably be explained by the fact that spraying takes place in the high-risk areas and this would point to a good targeting of the spraying activities by the AMC. By using a risk-map approach employing GIS tools, this targeting could be further improved. The discussions in the workshop that was organized for mid-level health managers in the study area showed that already the simple-incidence maps were regarded as a great help to monitor and target control activities (Klinkenberg 2001a, b). If maps could be created on a weekly or bimonthly basis consistently, an increase in the number of cases for specific areas could serve as a warning for the control agency to start control activities in these areas. However, for this purpose more detailed research on a specific threshold value for different areas will be necessary.

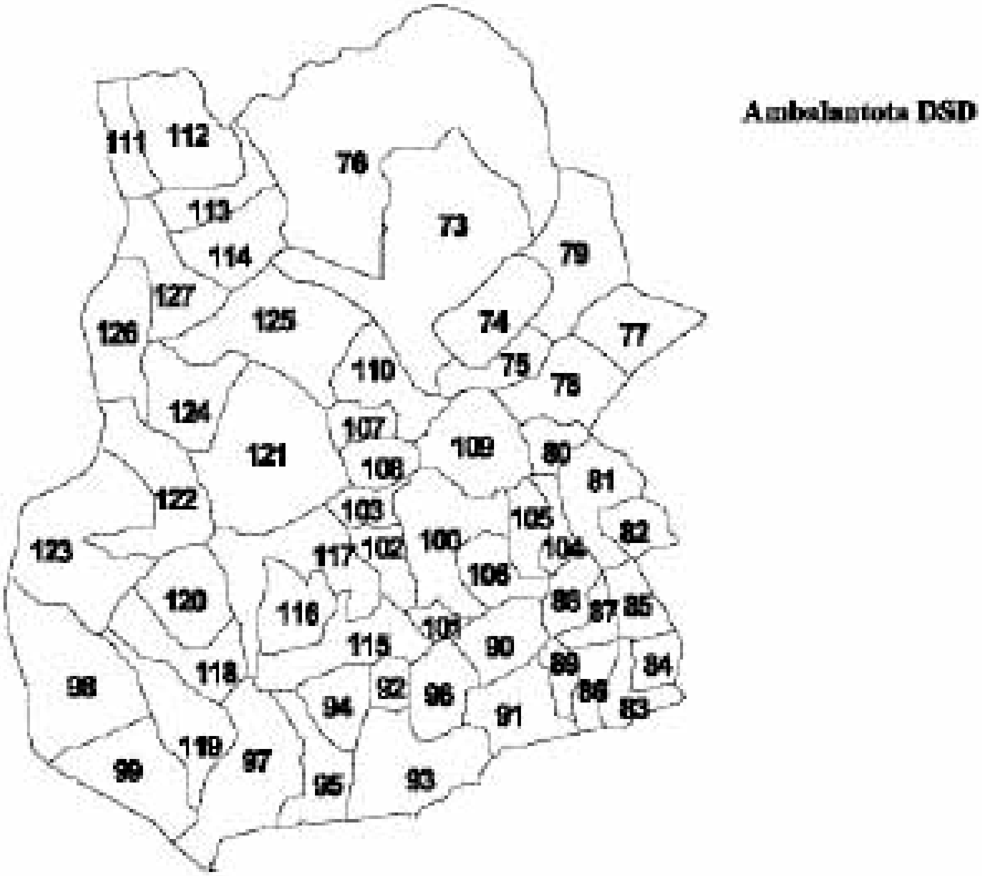
The study suggests that more insight is needed into the relative importance of different mosquito-vector species in malaria transmission. More research is also warranted on the importance of the socioeconomic status of the population in determining malaria risk.

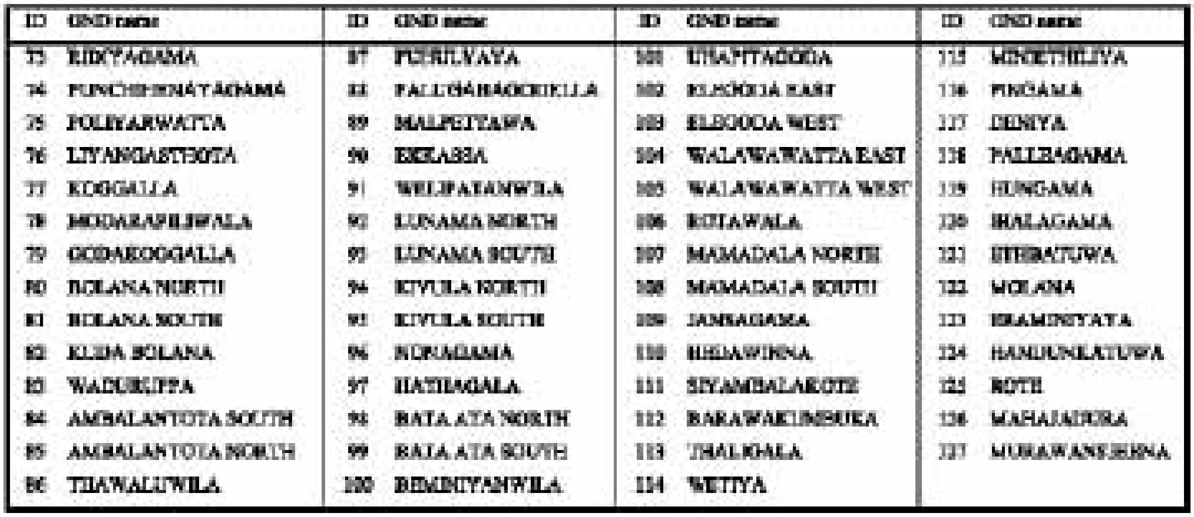
This study showed that malaria risk is higher outside the irrigated areas and is associated with chena cultivation, the presence of forests and abandoned tanks, and socioeconomic variables. The mapping of malaria incidence on a regular basis is considered a valuable tool for improved malaria control, in which resources and control efforts are concentrated in high-risk areas. This study also showed the importance of a standard system for data recording and systems that are compatible between different departments and institutions. As chena cultivation seemed to be an important factor in increased malaria incidence, special attention should be focused on these areas within the malaria-control program, as conventional control measures built around indoor-residual spraying might not be suitable for these areas.

Appendixes

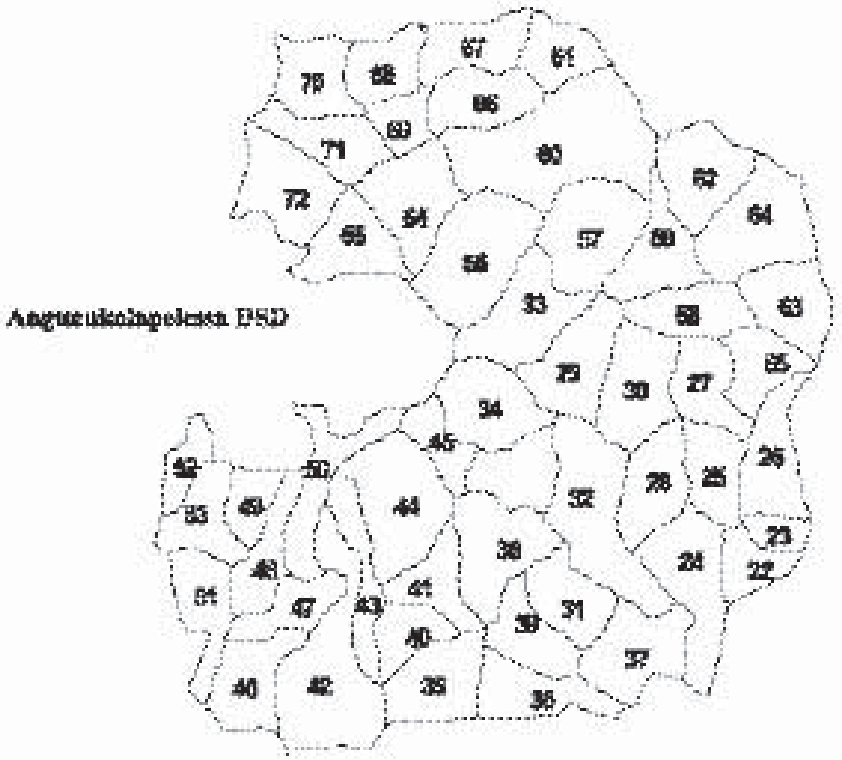
APPENDIX A.

Divison of GNDs within the different DSDs

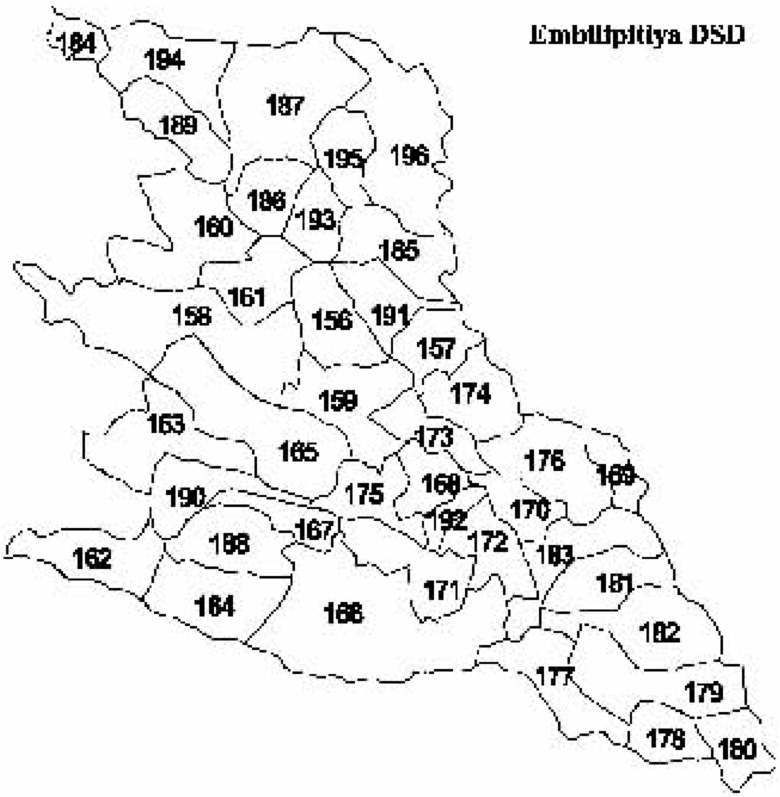




ID	GND name	ID	GND name	ID	GND name	ID	GND name
73	RIDIYAGAMA	87	PUHULYAYA	101	USAPITTAGODA	115	MINETHILIYA
74	PUNCHIHENAYAGAMA	88	PALLUGAHAKOKELLA	102	ELEGODA EAST	116	PINGAMA
75	POLIYARWATTA	89	MALPETTAWA	103	ELEGODA WEST	117	DENIYA
76	LIYANGASTHOTA	90	EKELASSA	104	WALAWAWATTA EAST	118	PALLEBAGAMA
77	KOGGALLA	91	WELIPATANWILA	105	WALAWAWATTA WEST	119	HUNGAMA
78	MODARAPILIWALA	92	LUNAMA NORTH	106	BOTAWALA	120	BALAGAMA
79	GODAKOGGALLA	93	LUNAMA SOUTH	107	MAMADALA NORTH	121	ETHBATUWA
80	BOLANA NORTH	94	KIVULA NORTH	108	MAMADALA SOUTH	122	MOLANA
81	BOLANA SOUTH	95	KIVULA SOUTH	109	JANSAGAMA	123	BRAMINIYAYA
82	KUDA BOLANA	96	NONAGAMA	110	HEDAWINNA	124	HANDUNKATUWA
83	WADURUPPA	97	HATHAGALA	111	SIYAMBALAKOTE	125	ROTE
84	AMBALANTOTA SOUTH	98	BATA ATA NORTH	112	BARAWAKUMBUKA	126	MAHAJADURA
85	AMBALANTOTA NORTH	99	BATA ATA SOUTH	113	THALIGALA	127	MURAWANSIHINA
86	THAWALUWILA	100	BEMINIYANWILA	114	WETIYA		

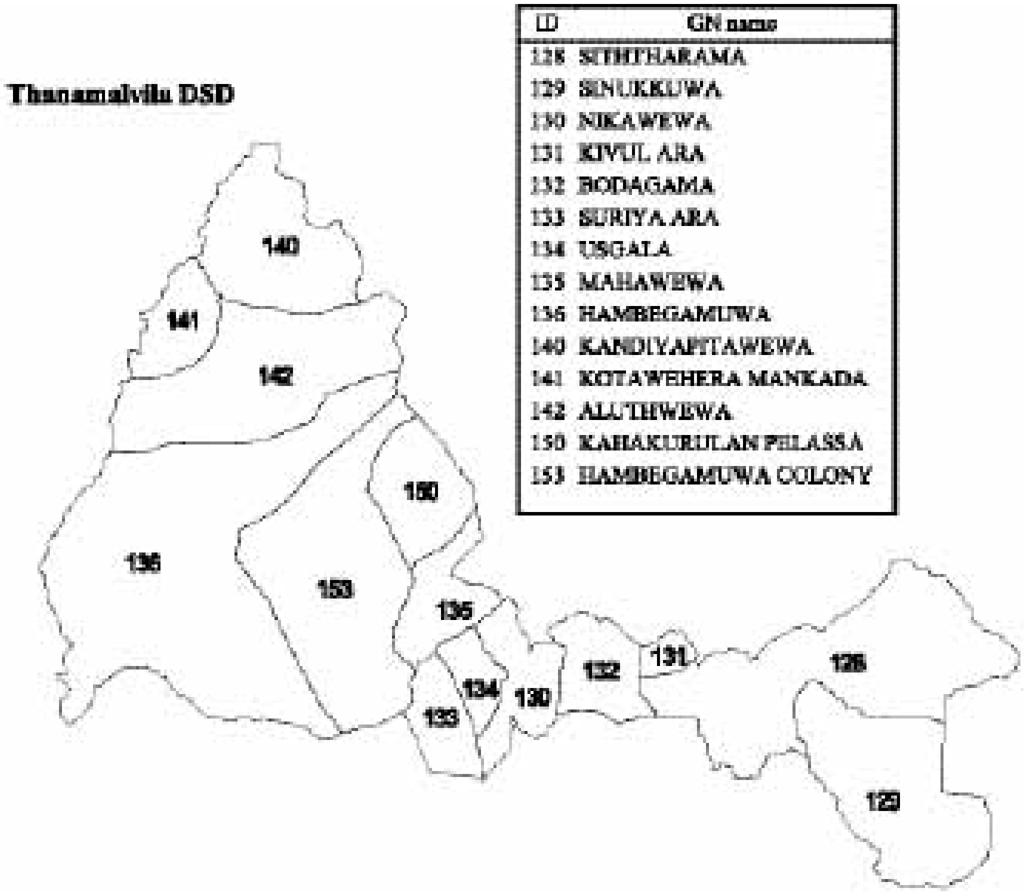


ID	GN name	ID	GN name	ID	GN name
22	ANGUNUKOLAPELESSA	39	KIYTAWAYA	56	SURIYAPOKUNA
23	ACHARIYAGAMA	40	KAKURUWIRA	57	AMARATHUNGAGAMA
24	YAKAGALA	41	NETHALAPURUWA	58	MEDA ARA
25	ALUTHWEWA	42	UDAYALA	59	KOHOMBAGASWEWA
26	KANKANAMGAMA	43	MEDAYALA	60	LUNUWEWA
27	BENKAMA	44	BOGAMUWA	61	KALAWELPOTHAWA
28	HELEKADA	45	WEERAGASWEWA	62	METIGATHWALA
29	BANDENIGAMA	46	HEERABUNNA	63	ABESEKARAGAMA
30	KARAGAHAWALA	47	MAKULADENIYA	64	DEKWEWA
31	JULAMULLA	48	MEDAGODA	65	KALAWELWALA
32	JANDORA	49	DEMBELGODA	66	EERIMAKETIYA
33	PAHALAGAMA	50	GAJANAYAKAGAMA	67	KATTIMALWALA
34	GORUWALA	51	WAKAMULLA	68	DABARELLA NORTH
35	BIRICKTAWELA	52	ATTANAYALA WEST	69	DABARELLA SOUTH
36	THALAMPORUWA	53	ATTANAYALA EAST	70	KARIYAMADITTA
37	GURUBANEHEGOD ARA	54	DESOKKAWA NORTH	71	THALAWA NORTH
38	DAHA AMUNA	55	DESOKKAWA SOUTH	72	THALAWA SOUTH



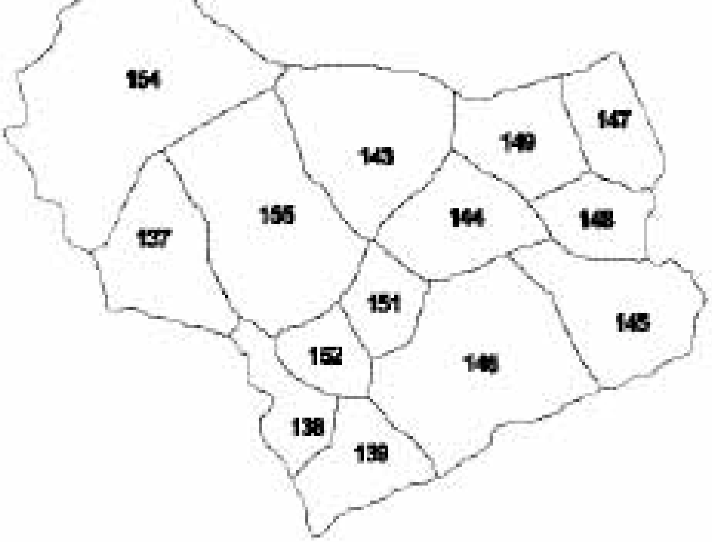
ID	GN name	ID	GN name	ID	GN name
156	MADUWANWELA	170	PALLEGAMA	184	PALLEBEDDA
157	GANGEYAYA	171	KUMBUGODA ARA	185	RATHKARAWA
158	RANCHAMADAMA	172	EBILITIYA NEW TOWN	186	KOLAMBAGE ARA
159	NINDAGAMPELASSA	173	HIGURA ARA	187	PANAHADUWA
160	MIRISWELPOTHA	174	KETAGALARA	188	SUDUGALA
161	ANDOLUWA	175	MODARAWANA	189	SANKAPALA
162	DIYAPOTHA	176	KALAGEDIARA	190	WALALLGODA
163	JANDURA	177	HIGURA	191	UDA WALAWE YAYA 2 WASAMA
164	MULANDIYAWALA	178	PADALANGALA	192	YODAGAMA
165	PANAMURA	179	KUTTIGALA	193	THIMBOLKETIYA
166	THORAKOLAYAYA	180	JULANGATE	194	THITHTHAWELPOTHA
167	KONEKADUWA	181	THUNKAMA	195	UDA WALAWE
168	EMBILIPITIYA UDAGAMA	182	HAGALA	196	UDA WALAWE WEWA
169	MORAKETIYA	183	HALMILLAKETIYA		

Thanamalvilu DSD



ID	GN name
128	SITHTHARAMA
129	SINUKKUWA
130	NIKAWEWA
131	KIVUL ARA
132	BODAGAMA
133	SURIYA ARA
134	USGALA
135	MAHAWEWA
136	HAMBEGAMUWA
140	KANDIYAPITAWEWA
141	KOTAWEHERA MANKADA
142	ALUTHWEWA
150	KAHAKURULAN PELASSA
153	HAMBEGAMUWA COLONY

Sevanagala DSD



ID	GN name
137	MUTUMINIGAMA
138	HABARATHTHAWELA
139	MAHAGAMA
143	HABARALUWEWA
144	KIRIBBANWEWA
145	NUGEGALAYAYA
146	HABURUGALA
147	WELI ARA
148	PUNCHIWEWA
149	SAMAGIPURA
151	INDIKOLAPELASSA
152	BAHIRAWA
154	KATUPILAGAMA
155	SEVANAGALA

Sooriyawewa DSD

ID	GN name	ID	GN name
1	WELIWEWA	12	ANDARAWEWA
2	RANMUDUWEWA	13	NAMADAGASWEWA
3	IHALA KUMBUKWEWA	14	MAHAWELIKADA ARA
4	MAHAGALWEWA	15	BEDDEWEWA
5	MEEGAHAJANDURA	16	ALIOLU ARA
6	SURIYAWEWA TOWN	17	HATHPORUWA
7	SURAVIRUGAMA	18	WEERIYAGAMA
8	SAMAJASEWAPURA	19	BEDIGAMTOTA
9	VIHARAGALA	20	WEDIWEWA
10	MAHA PELESSA	21	HABARATTAWALA
11	WENIWEL ARA		

APPENDIX B.

Details of variables considered in the study

Parameter	Data type	Lowest level available	Period collected	Data source	Remarks
No. of malaria cases	Malaria	Village	Monthly Jan.'91- Aug '00	hospital	
Population size	Population	GND		DS Office, C&S	Village-level data incomplete,available for 1993
Surface area	Basic	GND		DS Office	Obtained from digitized maps
No. of families	Basic	Village	1 yr., 1993	C&S	
No. of houses	Basic	Village	1 yr.., 1993	C&S	
No. of families receiving Janasavia or food-stamps	Socio-economic	Village	1 yr., 1993	C&S	
No. of families having their own house	Socio-economic	Village	1 yr., 1993	C&S	
No. of families having a rented house	Socio-economic	Village	1 yr., 1993	C&S	
No. of families having electricity	Socio-economic	Village	1 yr., 1993	C&S	
No. of landless families	Socio-economic	Village	1 yr., 1993	C&S	
No. of houses sprayed per village	Control	Village/GND	Several years, few areas, incomplete?	AMC	Available data collected, used at GND level to indicate presence of spraying
Usage of anti-mosquito measures (sometimes/never /always)	Control	Village	Restricted area,51 GNDs	IWMI	Data were collected in several, but not all, villages in 51 GNDs
What anti-mosquito measure used (bed net /coils/other)	Control	Village	Restricted area, 51 GNDs	IWMI	Data were collected in several, but not all, villages in 51 GNDs
No. of livestock	Land use	GND	1 yr., 1993	C&S	
Paddy cultivated area	Land use	GND	2 years, 1985, 1995/1997	SD ('85) LUPPD ('95/'97)	Area data obtained from areadigitized maps
Chena area	Land use	GND	2 years, 1985, 1995/1997	SD ('85) LUPPD ('95/'97)	Area data obtained from digitized maps

Continued

Coconut area	Land use	GND	2 years, 1985, 1995/1997	SD (‘85) LUPPD (’95/’97)	Area data obtained from digitized maps
Forest area	Land use	GND	2 years, 1985, 1995/1997	SD (‘85) LUPPD (’95/’97)	Area data obtained from digitized maps
Garden area	Land use	GND	2 years, 1985 , 1995/1997	SD (‘85) LUPPD (’95/’97)	Area data obtained from digitized maps
Scrub area	Land use	GND	2 years, 1985, 1995/1997	SD (‘85) LUPPD (’95/’97)	Area data obtained from digitized maps
Grassland area	Land use	GND	2 years, 1985, 1995/1997	SD (‘85) LUPPD (’95/’97)	Area data obtained from digitized maps
Other plantation area	Land use	GND	2 years, 1985, 1995/1997	SD (‘85) LUPPD (’95/’97)	Area data obtained from digitized maps
Marsh area	Land use	GND	2 years, 1985, 1995/1997	SD (‘85) LUPPD (’95/’97)	Area data obtained from digitized maps
Sand/Rock area	Land use	GND	2 years, 1985, 1995/1997	SD (‘85) LUPPD (’95/’97)	Area data obtained from digitized maps
Water area	Land use	GND	2 years, 1985, 1995/1997	SD(‘85) LUPPD (’95/’97)	Area data obtained from digitized maps
Tanks (working)	Land use	GND	2 years, 1985, 1995/1997	SD (‘85) LUPPD (’95/’97)	Area data obtained from digitized maps
Tanks (abandoned)	Land use	GND	2 years, 1985, 1995/1997	SD (‘85) LUPPD (’95/’97)	Area data obtained from digitized maps
Rainfall	Climate	GND	Monthly, June 1999-May 2000	Met. Dep.	Several rain-station data interpolated
Soil moisture	Climate	GND	Monthly, June 1999-May 2000	Met. Dep.	NOAA satellite images

Note: C&S = Department of Census and Statistics, Sri Lanka; SD = Survey Department, Sri Lanka; LUPPD = Land Use Policy Planning Division, Sri Lanka; Met. Dep. = Meteorological Department; IWMI = Questionnaire survey carried out by IWMI researchers in the Uda Walawe area.

APPENDIX C.

Availability of hospital data and microscopist within the hospitals

TABLE 1.

Availability of hospital data in the different hospitals for the period 1991-2000.

Hospital	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Ambalantota PU	1	1	1	1	1	1	1	1	1	1
Angunukolapelessa PU	1	1	1	1	1	1	1	1	1	3
Chandrika Wewa DH	1	1	1	1	1	1	1	1	1	3
Embilipitiya BH	1	1	1	1	1	1	1	1	1	3
Hakuruwela RH	1	1	1	0	0	0	0	0	1	3
Hambagamuwa PU	1	1	1	1	1	1	1	1	1	3
Kariyamaditta DH	1	1	1	1	1	1	0	0	0	3
Mullediyawala CD	1	1	1	1	1	1	1	1	1	3
Pallebedda DH	1	1	1	1	1	1	1	1	1	3
Ridyagama CD	0	0	0	1	1	1	1	1	1	3
Sevenegala RH	0	0	0	0	0	0	1	1	1	3
Suriyawewa RH	3	0	3	3	3	1	1	1	1	1
Thanamalvila DH	1	1	1	1	1	1	1	1	1	3
Uda Walawe RH*	0	0	0	0	0	0	1	1	1	3
MTC Uva Kuda oya Oya	0	0	0	0	0	0	0	3	1	3

Note: BH = Base Hospital; PU = Peripheral Unit; DH = District Hospital; RH = Regional Hospital; CD = Central Dispensary; * Uda Walawe was a CD till 1997 when it was upgraded to an RH. 1= complete; 0 = absent; 3 = incomplete; *was formerly a CD that became an RH in 1999/2000.

TABLE 2.

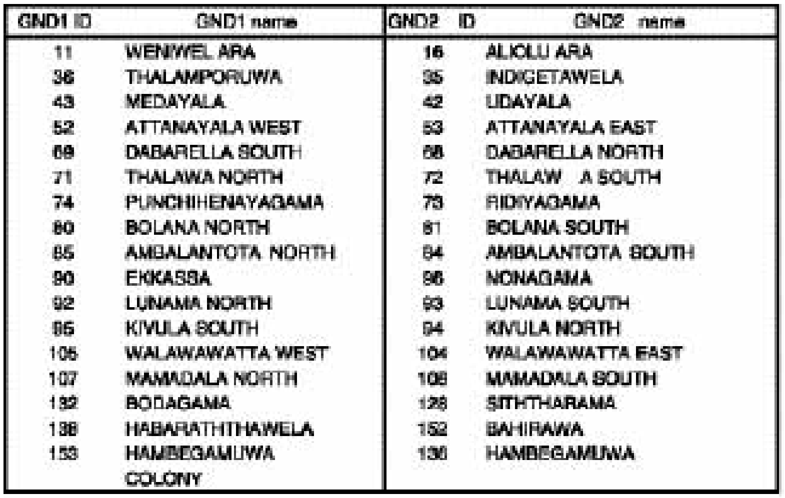
Presence of microscopist and field assistants in the hospitals during the study period.

Hospital	Availability microscopist and field assistant (FA)
Ambalantota PU	Microscopist from February 1994. FA present throughout. During this period BF sent to RMO, Hambantota.
Angunukolapelessa PU	No microscopist (cadre) available. FA available throughout. BF sent to Ambalantota.
Chandrika Wewa DH	Microscopist and FA available from 1989 onwards.
Embilipitiya BH	Microscopist and FA available throughout.
Hakuruwela RH	No microscopist. FA available 1991-1993.
Hambagamuwa PU	Trainee microscopist available from April to June 1999. Previously only in 1992. BF sent to Badulla.
Kariyamaditta DH	No microscopist available. No FA since May 1997.
Mullediyawala CD	No microscopist. FA present throughout. BF sent to Embilipitiya BH.
Pallebedda DH	Microscopist available throughout from 1989 onwards; FA from 1988 onwards.
Ridyagama CD	No microscopist. FA first appointed in February 1995. BF sent to Ambalantota PU.
Sevenegala RH	No microscopist during 1991-1998. Sevanagala was CD & MH till 1998. FA from time to time and currently from December 1996.
Suriyawewa RH	Microscopist available from August 1995. Relief microscopist before that. Previously BF sent to RMO Hambantota. FA continuously from February 1994.
Thanamalvila DH available	Microscopist available but only 4 to 5 days a week. Available throughout from 1970 onwards. FA throughout.
Uda Walawe RH*	Although microscopist was available the FA was discontinuous. Therefore, data are available only for 1997/1998 with RMO, Embilipitiya. Data at RH (earlier CD&MH) and still not functioning as an RH available from 1999 onwards.
MTC Uva Kuda oya	Malaria Treatment Centre started in July 1998.

Note: BH = Base Hospital; PU = Peripheral Unit; DH = District Hospital; RH = Regional Hospital; CD = Central Dispensary; * Uda Walawe was a CD till 1997 when it was upgraded to an RH; BF= Blood Films.

APPENDIX D.

GND units that are merged because villages overlap GND boundaries



GND1 ID	GND1 name	GND2 ID	GND2 name
11	WENIWEL ARA	16	ALIOLU ARA
36	THALAMPORUWA	35	INDIGETAWELA
43	MEDAYALA	42	UDAYALA
52	ATTANAYALA WEST	53	ATTANAYALA EAST
69	DABARELLA SOUTH	68	DABARELLA NORTH
71	THALAWA NORTH	72	THALAW A SOUTH
74	PUNCHIHENAYAGAMA	73	RIDIYAGAMA
80	BOLANA NORTH	81	BOLANA SOUTH
85	AMBALANTOTA NORTH	84	AMBALANTOTA SOUTH
90	EKKASSA	96	NONAGAMA
92	LUNAMA NORTH	93	LUNAMA SOUTH
95	KIVULA SOUTH	94	KIVULA NORTH
105	WALAWAWATTA WEST	104	WALAWAWATTA EAST
107	MAMADALA NORTH	108	MAMADALA SOUTH
132	BODAGAMA	128	SITHTHARAMA
138	HABARATHTHAWELA	152	BAHIRAWA
153	HAMBEGAMUWA COLONY	136	HAMBEGAMUWA

APPENDIX E.

Data considerations

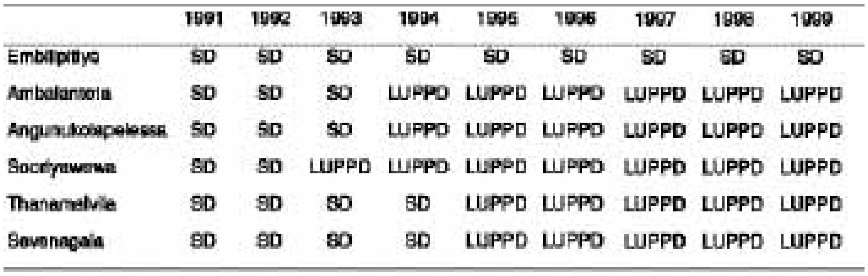
GPS Coordinates

Coordinates were taken in the geographical projection system as longitude-latitude with the Kandawela datum. Locating the villages in the field was organized as follows: For each hospital, a list of names of the villages from which people had reported to the respective hospital was created. The villages were located by asking directions from inhabitants in the area around the hospital, and GPS coordinates were taken of each located village. The coordinates were always taken at the school, the temple or another common place within the village. People in the village were asked for other names used for their village to cross-check with the official list of names of villages. Nearly all of the villages (94%) could be located in this way. Eight villages could not be located and since each of several of them had only one case recorded, it was assumed that the malaria patients were visitors from outside the area. One village did not exist any longer as it had become part of the Uda Walawe National Park area and people there were relocated several years ago. Villages that could not be located or were located outside the study area were excluded from the analysis. When there were identical names for villages, the case data were assigned to the village closest to the hospital where the case data were recorded.

Land-Use Maps

Land-use data were collected from two sources, the Survey Department and the Land Use Policy Planning Division (LUPPD). The Survey Department maps were updated maps from original one-inch to one-mile maps and for the major part of the study area the last field revision was carried out in 1983-1984. The LUPPD had maps at the DSD level for five of the six DSDs. The year of the most recent map differed per DSD: for Sooriyawewa DSD this was 1995, for Ambalantota DSD 1996, for Thanamalvila and Sevenagala DSDs 1998, and for Angunukolapelessa DSD 1996. For Embilipitiya DSD the situation was slightly different. The LUPPD for that district was preparing very detailed land-use maps at 1:10,000 scale for the whole DSD. The maps were drawn but the cross-checking in the field was not finished and, therefore, these maps could not be used. The Survey Department land-use pattern was manually checked with the detailed LUPPD ones, revealing that, in general, most areas were similar in land use although a significant part of chena was being transformed into paddy or other plantations. Manual adjustment of the existing layer would lead to large insecurities due to the difference in scale between the old and the updated maps. Therefore, it was decided to use only the land-use pattern from the Survey Department maps for Embilipitiya DSD. To reflect the change in land use that would have occurred between 1990 and 2000, the maps of both departments were used. Table 1 indicates the data considerations for the land-use data. The LUPPD and Survey Department maps used slightly different categories of land use but they could all be transformed into the broader categories used for the data analysis, i.e., paddy, chena, other crops (coconut, banana, other plantations, and home gardens, including settlement, scrubland including grassland and barren land), forest, water (tanks, rivers and lagoons), abandoned tanks, working tanks, rock (including sand) and marsh. The category of settlement and playgrounds, demarcated only on a few maps and representing less than one percent of land use, was included within the category of home gardens within which the bulk of settlement areas were classified. The maps of the LUPPD did not have abandoned tanks as a category of land use. Discussion with the respective LUPPD offices revealed that abandoned tanks were not recorded as such in their classification. Therefore, the layer of abandoned tanks from the Survey Department map was integrated in the LUPPD map using GIS techniques, as otherwise this covariate would have to be excluded for the larger part of the analysis.

TABLE 1.
Overview of the land-use map source used for the different DSDs for the period 1991-1999.



	1991	1992	1993	1994	1995	1996	1997	1998	1999
Embilipitiya	SD	SD	SD	SD	SD	SD	SD	SD	SD
Ambalantota	SD	SD	SD	LUPPD	LUPPD	LUPPD	LUPPD	LUPPD	LUPPD
Angunukolapelessa	SD	SD	SD	LUPPD	LUPPD	LUPPD	LUPPD	LUPPD	LUPPD
Sooriyawewa	SD	SD	LUPPD	LUPPD	LUPPD	LUPPD	LUPPD	LUPPD	LUPPD
Thanamalvila	SD	SD	SD	SD	LUPPD	LUPPD	LUPPD	LUPPD	LUPPD
Sevanagala	SD	SD	SD	SD	LUPPD	LUPPD	LUPPD	LUPPD	LUPPD

Note: SD = Maps of the Survey Department, Sri Lanka; LUPPD = Maps of the Land Use Policy Planning Division, Sri Lanka.

APPENDIX F.

Method of calculating soil moisture

Since there is no operationally feasible method to estimate the soil-water content of the root zone an empirical relationship between soil moisture and the heat fluxes partitioning ratio (called Evaporative Fraction: Λ) proposed in Bastiaanssen et al. 2000 was integrated with RS data to estimate soil moisture. is the output of SEBAL (Bastiaansen et al. 2000), and is defined as the ratio of latent heat to net available energy as in the equation below:

$$\Lambda = \frac{\lambda E}{Q^* - G_0} = \frac{Q^* - G_0 - H}{Q^* - G_0} \qquad (-) \qquad (1)$$

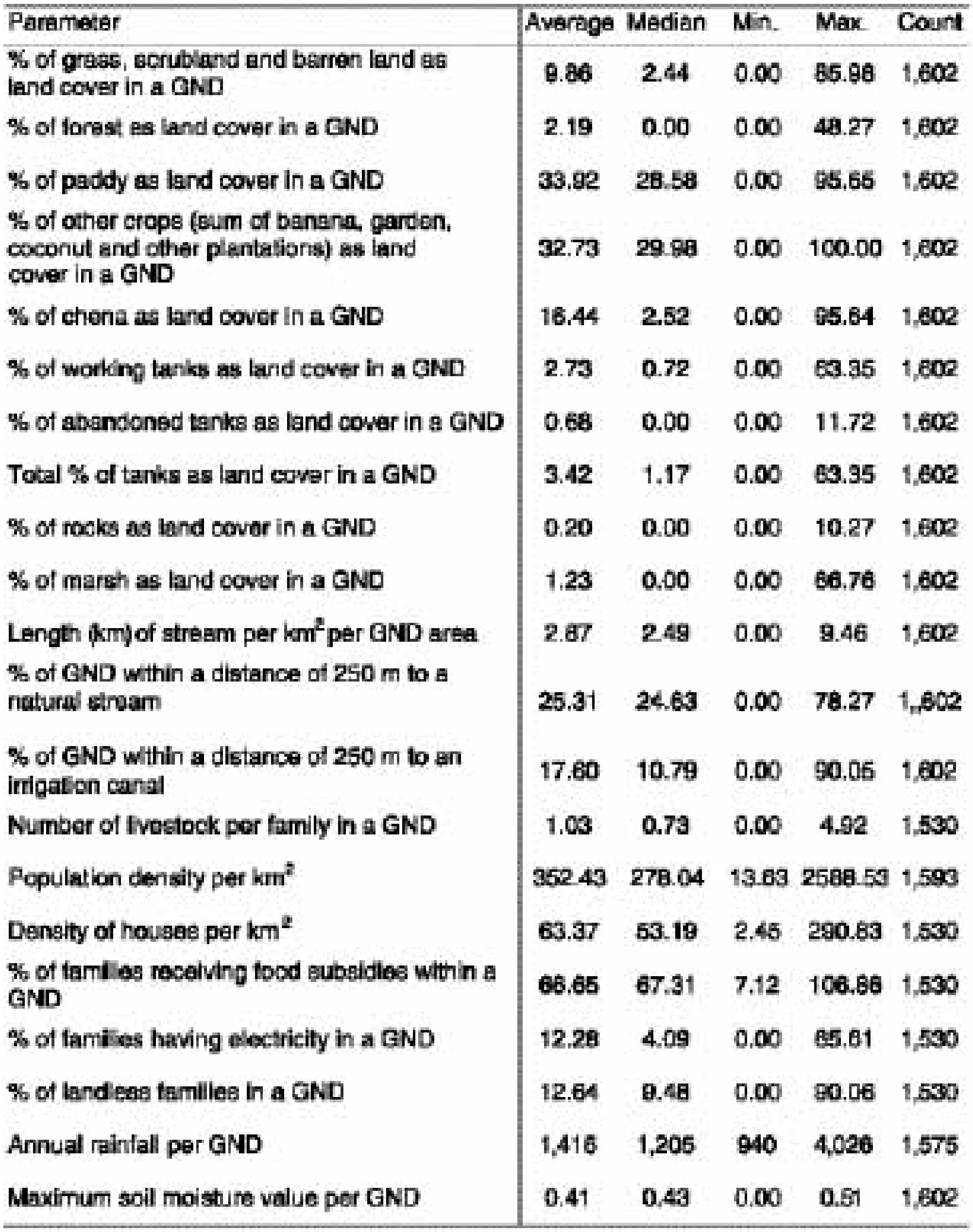
where, = the Evaporative Fraction *(-)*, Q^* = the Instantaneous Net Radiation *(W/m^2)*, = the Instantaneous Soil Heat Flux *(W/m^2)*, H = the Instantaneous Sensible Heat Flux *(W/m^2)* and λE = the Instantaneous Latent Heat of Vaporization *(W/m^2)*. The empirical relationship between the root zone soil moisture and Λ, after Bastiaanssen et al. 2000, is as follows:

$$\theta = 0.0475 \times e^{2.3736 \times \Lambda} \qquad (cm^3/cm^3) \qquad (2)$$

where, θ = the root zone soil moisture. These results are valid for the experiments made under the conditions found in the USA and Spain; however, it was the only information available for this study. Soil moisture was calculated assuming a constant soil porosity, across the island, of 0.51 cm^3 cm^{-3}, being the upper limit of this empirical equation, setting the typical soil conditions at 100 percent soil-water content saturation in the root zone of the soil when this value is reached.

APPENDIX G.

Descriptive statistics of variables considered in the study

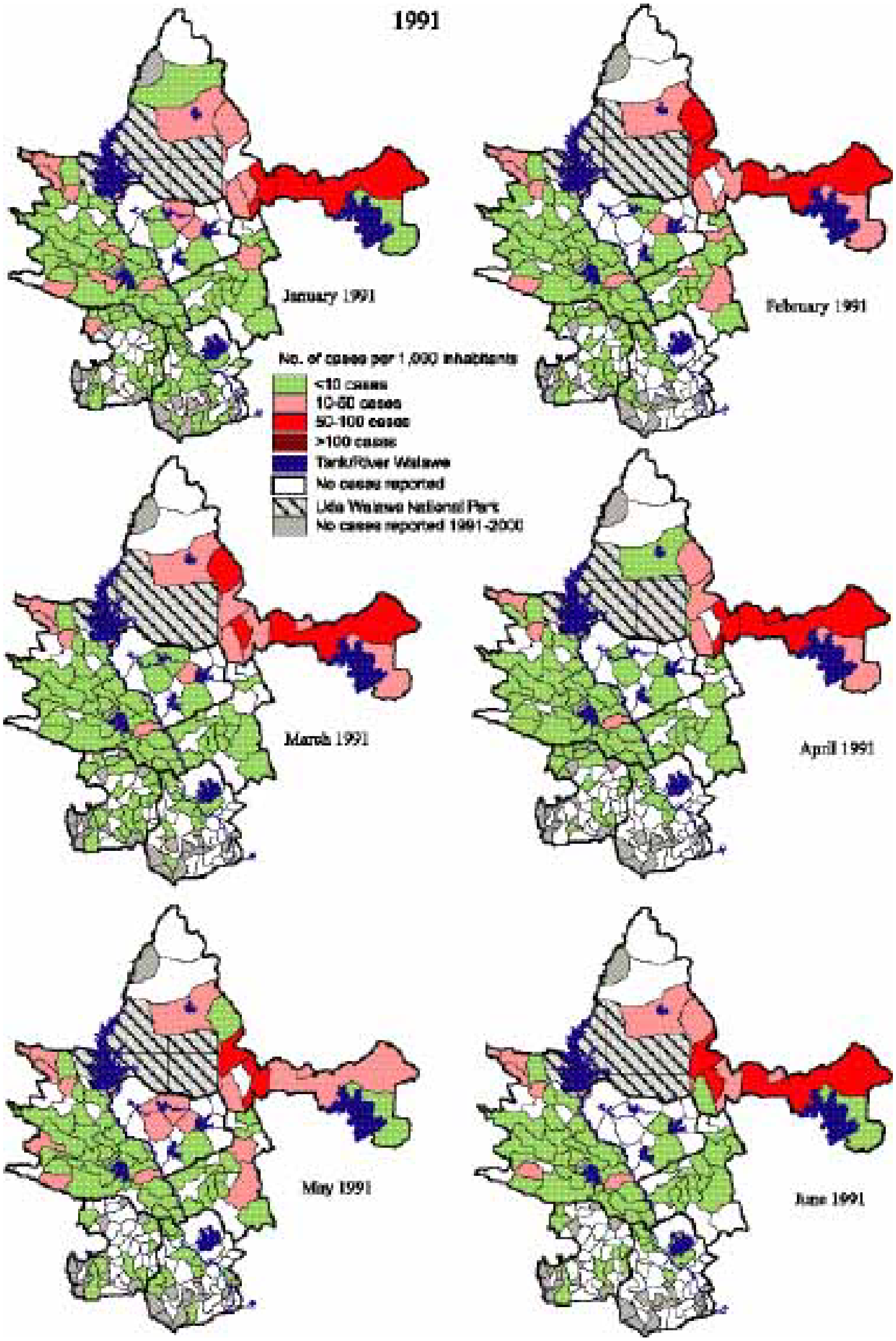


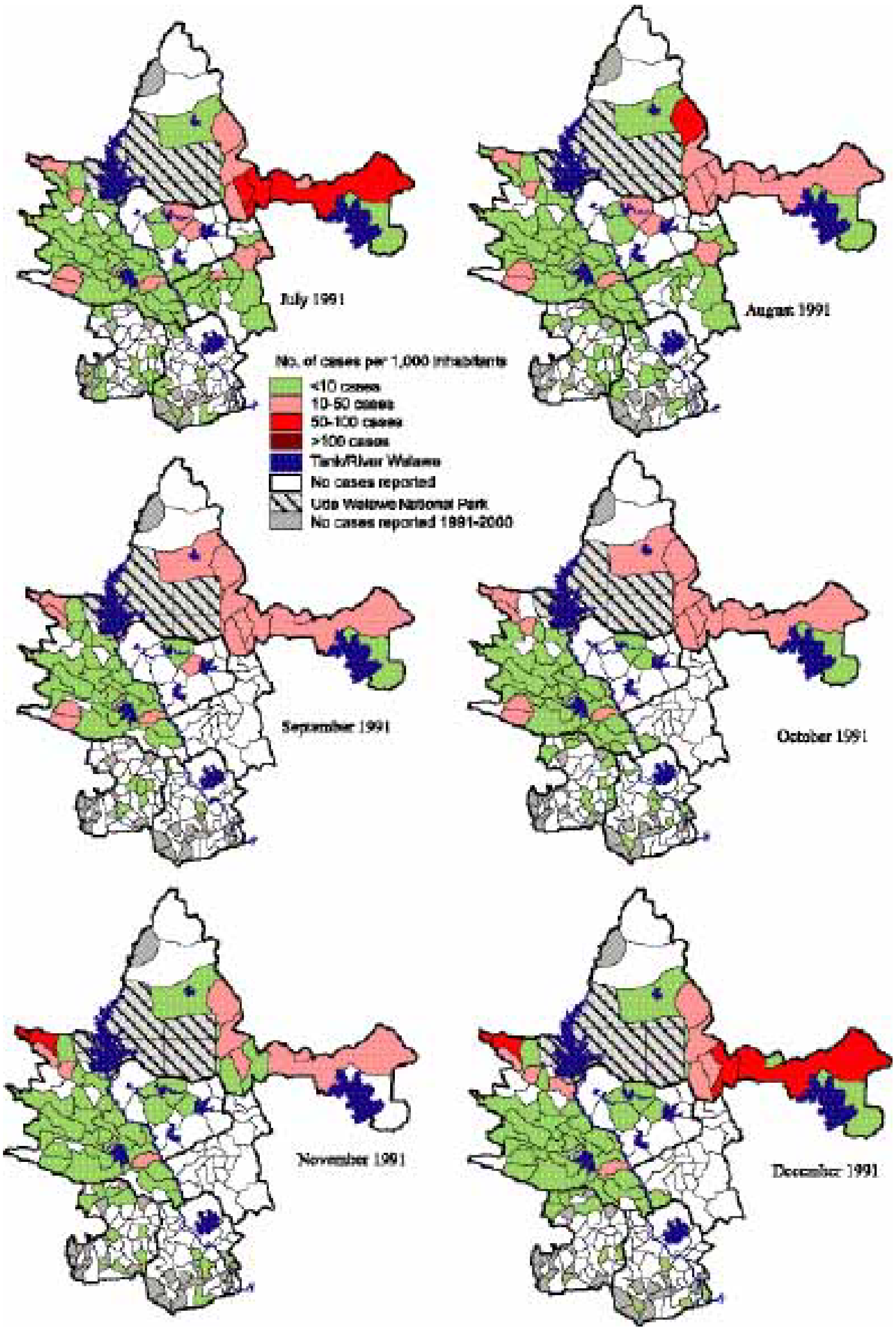
Parameter	Average	Median	Min.	Max.	Count
% of grass, scrubland and barren land as land cover in a GND	9.86	2.44	0.00	85.98	1,602
% of forest as land cover in a GND	2.19	0.00	0.00	48.27	1,602
% of paddy as land cover in a GND	33.92	28.58	0.00	95.65	1,602
% of other crops (sum of banana, garden, coconut and other plantations) as land cover in a GND	32.73	29.98	0.00	100.00	1,602
% of chena as land cover in a GND	16.44	2.52	0.00	95.64	1,602
% of working tanks as land cover in a GND	2.73	0.72	0.00	63.35	1,602
% of abandoned tanks as land cover in a GND	0.68	0.00	0.00	11.72	1,602
Total % of tanks as land cover in a GND	3.42	1.17	0.00	63.35	1,602
% of rocks as land cover in a GND	0.20	0.00	0.00	10.27	1,602
% of marsh as land cover in a GND	1.23	0.00	0.00	66.76	1,602
Length (km) of stream per km^2 per GND area	2.87	2.49	0.00	9.46	1,602
% of GND within a distance of 250 m to a natural stream	25.31	24.63	0.00	78.27	1,,602
% of GND within a distance of 250 m to an irrigation canal	17.60	10.79	0.00	90.05	1,602
Number of livestock per family in a GND	1.03	0.73	0.00	4.92	1,530
Population density per km^2	352.43	278.04	13.63	2588.53	1,593
Density of houses per km^2	63.37	53.19	2.45	290.63	1,530
% of families receiving food subsidies within a GND	66.65	67.31	7.12	106.86	1,530
% of families having electricity in a GND	12.28	4.09	0.00	85.61	1,530
% of landless families in a GND	12.64	9.48	0.00	90.06	1,530
Annual rainfall per GND	1,416	1,205	940	4,026	1,575
Maximum soil moisture value per GND	0.41	0.43	0.00	0.51	1,602

Note: Where the median value is 0, a cutoff criterion of 1% was used to obtain an effective equivalent value of less than, or equal to, zero. For these variables 1 indicates presence and 0 indicates absence.

APPENDIX H.

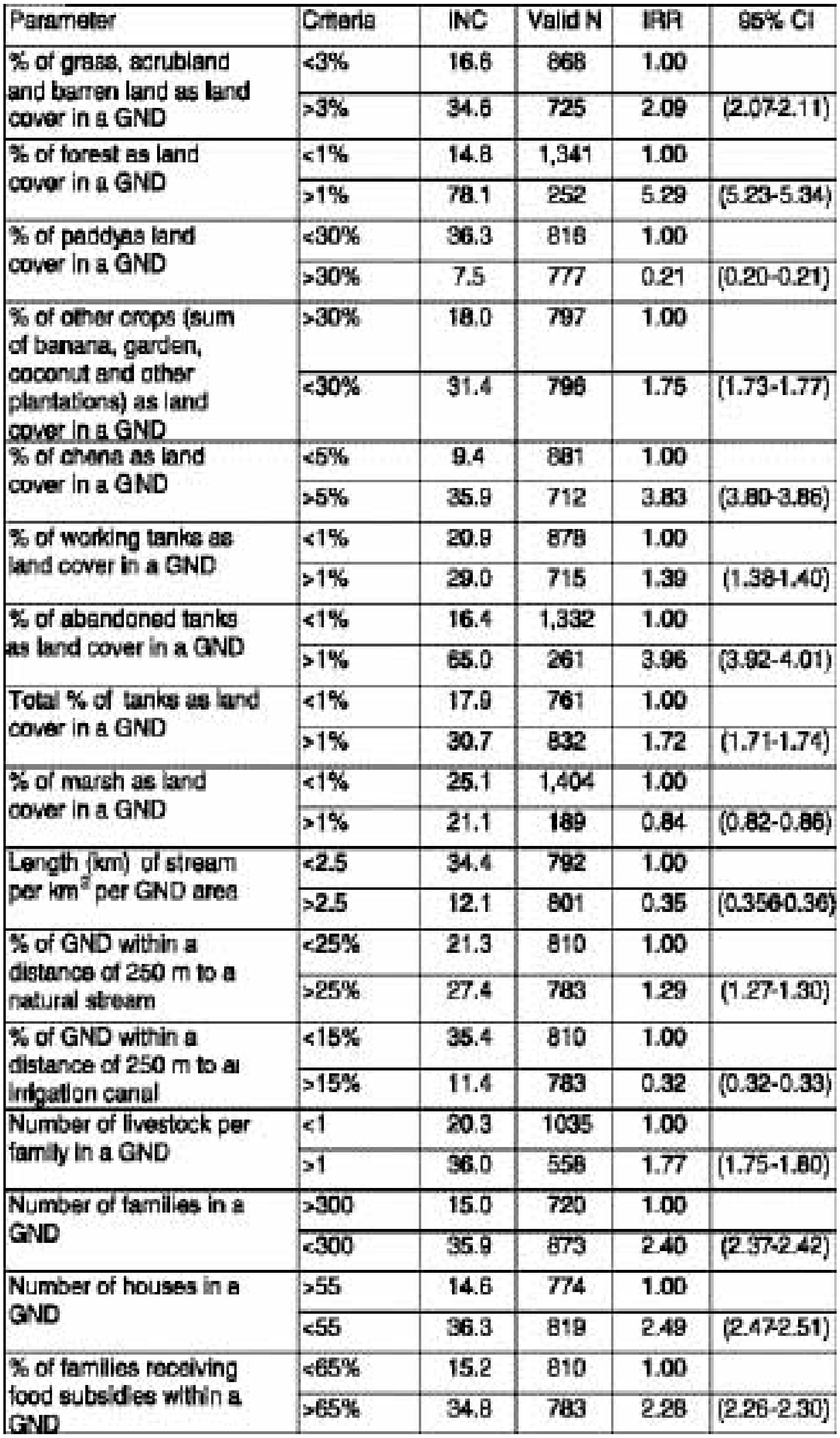
Malaria incidence at GND level per month for 1991




July 1991
August 1991
No. of cases per 1,000 inhabitants
🟩 <10 cases
🟥 10-50 cases
🟥 50-100 cases
🟥 >100 cases
🟦 Tank/River Wewas
☐ No cases reported
▨ Uda Walawe National Park
⬜ No cases reported 1991-2000
September 1991
October 1991
November 1991
December 1991

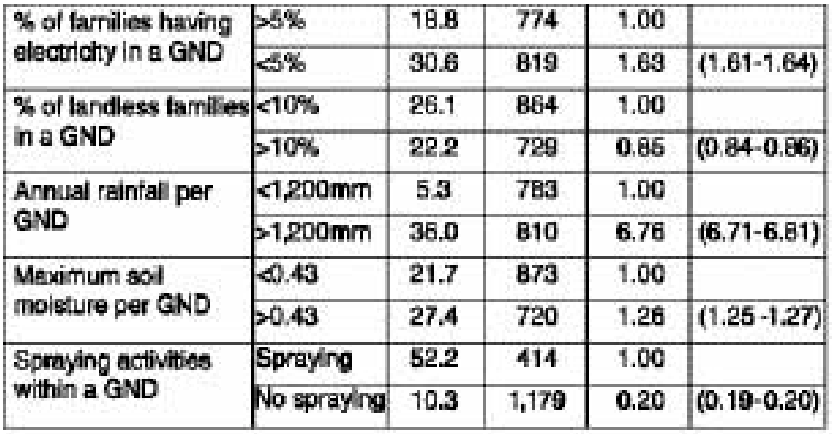
APPENDIX I.

Calculations of rates ratios for the different variables



Parameter	Criteria	INC	Valid N	IRR	95% CI
% of grass, scrubland and barren land as land cover in a GND	<3%	16.6	868	1.00	
	>3%	34.6	725	2.09	(2.07-2.11)
% of forest as land cover in a GND	<1%	14.8	1,341	1.00	
	>1%	78.1	252	5.29	(5.23-5.34)
% of paddyas land cover in a GND	<30%	36.3	816	1.00	
	>30%	7.5	777	0.21	(0.20-0.21)
% of other crops (sum of banana, garden, coconut and other plantations) as land cover in a GND	>30%	18.0	797	1.00	
	<30%	31.4	796	1.75	(1.73-1.77)
% of chena as land cover in a GND	<5%	9.4	881	1.00	
	>5%	35.9	712	3.83	(3.80-3.86)
% of working tanks as land cover in a GND	<1%	20.9	878	1.00	
	>1%	29.0	715	1.39	(1.38-1.40)
% of abandoned tanks as land cover in a GND	<1%	16.4	1,332	1.00	
	>1%	65.0	261	3.96	(3.92-4.01)
Total % of tanks as land cover in a GND	<1%	17.9	761	1.00	
	>1%	30.7	832	1.72	(1.71-1.74)
% of marsh as land cover in a GND	<1%	25.1	1,404	1.00	
	>1%	21.1	189	0.84	(0.82-0.86)
Length (km) of stream per km^2 per GND area	<2.5	34.4	792	1.00	
	>2.5	12.1	801	0.35	(0.3560.36)
% of GND within a distance of 250 m to a natural stream	<25%	21.3	810	1.00	
	>25%	27.4	783	1.29	(1.27-1.30)
% of GND within a distance of 250 m to ai irrigation canal	<15%	35.4	810	1.00	
	>15%	11.4	783	0.32	(0.32-0.33)
Number of livestock per family in a GND	<1	20.3	1035	1.00	
	>1	36.0	558	1.77	(1.75-1.80)
Number of families in a GND	>300	15.0	720	1.00	
	<300	35.9	873	2.40	(2.37-2.42)
Number of houses in a GND	>55	14.6	774	1.00	
	<55	36.3	819	2.49	(2.47-2.51)
% of families receiving food subsidies within a GND	<65%	15.2	810	1.00	
	>65%	34.8	783	2.28	(2.26-2.30)

Continued

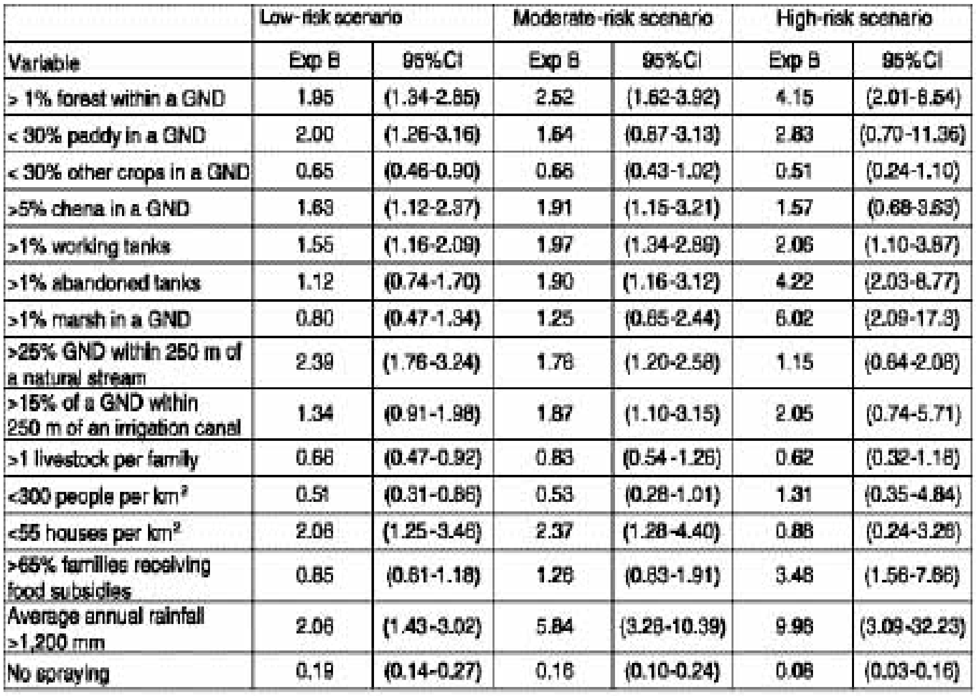


% of families having electricity in a GND	>5%	18.8	774	1.00	
	<5%	30.6	819	1.63	(1.61-1.64)
% of landless families in a GND	<10%	26.1	864	1.00	
	>10%	22.2	729	0.85	(0.84-0.86)
Annual rainfall per GND	<1,200mm	5.3	783	1.00	
	>1,200mm	36.0	810	6.76	(6.71-6.81)
Maximum soil moisture per GND	<0.43	21.7	873	1.00	
	>0.43	27.4	720	1.26	(1.25-1.27)
Spraying activities within a GND	Spraying	52.2	414	1.00	
	No spraying	10.3	1,179	0.20	(0.19-0.20)

Note: INC (incidence rate) = total number of cases of malaria of all GNDs that scored 1 for the specific parameter/ midyear population size of the GNDs * 1,000; IRR = incidence rate ratio; the score of 1 (reference category) was assigned to the category of the parameter that was expected to be associated with the highest risk; data for the period 1991-1999 (the year 2000 was incomplete and this year was therefore omitted form the analysis). Note, for example, an IRR of 2.09 for > 3% of grass, scrubland and barren land as land cover in a GND means that there is approximately twice the incidence rate in areas with > 3% land cover of grass, scrub and barren land, when compared with areas with < 3% of the same cover type.

APPENDIX J.

Results of logistic regression analyses for three different scenarios



	Low-risk scenario		Moderate-risk scenario		High-risk scenario	
Variable	Exp B	95%CI	Exp B	95%CI	Exp B	95%CI
> 1% forest within a GND	1.95	(1.34-2.85)	2.52	(1.62-3.92)	4.15	(2.01-8.54)
< 30% paddy in a GND	2.00	(1.26-3.16)	1.64	(0.87-3.13)	2.83	(0.70-11.36)
< 30% other crops in a GND	0.65	(0.46-0.90)	0.66	(0.43-1.02)	0.51	(0.24-1.10)
>5% chena in a GND	1.63	(1.12-2.37)	1.91	(1.15-3.21)	1.57	(0.68-3.63)
>1% working tanks	1.55	(1.16-2.09)	1.97	(1.34-2.88)	2.06	(1.10-3.87)
>1% abandoned tanks	1.12	(0.74-1.70)	1.90	(1.16-3.12)	4.22	(2.03-8.77)
>1% marsh in a GND	0.80	(0.47-1.34)	1.25	(0.65-2.44)	6.02	(2.09-17.3)
>25% GND within 250 m of a natural stream	2.39	(1.76-3.24)	1.76	(1.20-2.58)	1.15	(0.64-2.08)
>15% of a GND within 250 m of an irrigation canal	1.34	(0.91-1.98)	1.87	(1.10-3.15)	2.05	(0.74-5.71)
>1 livestock per family	0.66	(0.47-0.92)	0.83	(0.54-1.26)	0.62	(0.32-1.18)
<300 people per km²	0.51	(0.31-0.86)	0.53	(0.28-1.01)	1.31	(0.35-4.84)
<55 houses per km²	2.08	(1.25-3.46)	2.37	(1.28-4.40)	0.88	(0.24-3.26)
>65% families receiving food subsidies	0.85	(0.61-1.18)	1.26	(0.83-1.91)	3.48	(1.56-7.86)
Average annual rainfall >1,200 mm	2.08	(1.43-3.02)	5.84	(3.28-10.39)	9.96	(3.09-32.23)
No spraying	0.19	(0.14-0.27)	0.16	(0.10-0.24)	0.06	(0.03-0.16)

Notes: Low-risk scenario API>10 scored 1; moderate-risk scenario API>30 scored 1; high-risk scenario API >100 scored 1. Note that only parameters significant within at least one of the scenarios are shown. Note also that, for example, a high forest cover (>1% of the GND) has a 1.95 times higher risk of an API>10 than a low forest cover (<1%).

Logistic regression is of the form Prob(event)/ Prob(no event) = $e^{B0 + B1 X1 + B2 X2 + ...+ Bp Xp}$, such that Exp(Bi) is the factor by which the odds change when the i^{th} covariate changes by one unit. For the covariates as categorized in this analysis, Exp(B_i) is the odds ratio of category coded as 1 relative to category coded as 0.

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