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PLASMODIUM FALCIPARUM PARASITE PREVALENCE IN EAST AFRICA: A REVIEW
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PLASMODIUM FALCIPARUM PARASITE PREVALENCE IN EAST AFRICA: A REVIEW

J. A. OMUMBO and R.W. SNOW

ABSTRACT

Objectives: **Empirical data on malaria endemicity are rarely available for public domain use to guide effective malaria control. This paper describes the work carried in East Africa since 1997 as part of a pan-African collaboration to map the risk of malaria, Mapping Malaria Risk in Africa (MARA) aimed at redressing deficiency.**

Data extraction: **Studies of cross-sectional community estimates of *Plasmodium falciparum* prevalence among children aged 0-15 years were identified from a variety of sources including electronic searches of published material, manual review of pre-electronic peer reviewed journals and searches of libraries and archives in Kenya, Tanzania and Uganda. Each survey source, infection prevalence, date, longitude and latitude and survey characteristics were recorded.**

Data synthesis: **All data were subjected to a number of selection criteria including minimum sample sizes, samples randomly selected, community-based surveys, age ranges of sampled communities within 0-15 years, and surveys that were spatially unique. Of the 2,003 survey data points identified since 1907 in East Africa, only 503 were eligible for inclusion in the analysis dating from 1927 to 2003. The spatial plots of the data demonstrate the paucity of information on malaria prevalence from a number of densely populated areas and highlight the concentration of empirical data in concert with research centres in the sub-region.**

Conclusions: **Models are required to define malaria risk in areas of East Africa where no empirical data are available so that limited resources can be better targeted to those in greatest need.**

INTRODUCTION

Malaria continues to be a major public health problem in the East African sub-region. The disease overwhelms already stretched clinical services and contributes to at least a quarter of all deaths that occur before the fifth birthday(1). Furthermore there is convincing evidence that mortality directly due to *Plasmodium falciparum* is increasing in East Africa since the late 1980's coincidental with the emergence of resistance to widely used anti-malarial drugs(2).

The international community has been effective in raising the importance of malaria control as a priority health investment for Africa through the Roll Back Malaria (RBM) partnership (3,4). Nevertheless five years after the formation of RBM, countries in East Africa still have very low coverage of interventions likely to reduce the burden of malaria in this sub-region. National surveys in East Africa show that less than 5% of children less than five years old are protected by an insecticide-treated net (ITN)(5). In addition there are large disparities in the spatial components of access to ITN in all these countries. A recent Demographic and Health Survey in Kenya showed that the highest rates of ITN use were in Nairobi, the province least likely to experience malaria risk(6).

Malaria is a vector-borne disease whose geographical extent is driven largely by climatic factors affecting vector and parasite survival. Consequently the large diversity in climate, ecology and urbanisation, characteristic of East Africa, supports a wide range of infection and disease risks. It has often been argued that without at least a basic knowledge of risk, efforts to control malaria will lack the ability to target limited resources to maximise coverage appropriately among those most at risk(7).

There are several approaches to measuring malaria risk, but the most widely used in Africa today was developed following the conference on malaria eradication for Africa held in Kampala in 1950(8). Metselaar and van Theil proposed the use of community-derived estimates of the *P. falciparum* parasite prevalence among children aged 2-10 years(9). They categorised

malaria risk according to the prevalence of parasitaemia [the parasite rate (PR)] among two to ten year olds as follows: Hypoendemic if the PR in the two to ten year age group is <10%; mesoendemic if the PR is 11-50%; hyperendemic if the PR is constantly >50%; and holoendemic if the PR among infants (<1 year old) is constantly <75%. These criteria have been variously applied in different studies and modified according to the data available.

The simplicity of the measure has meant that it rapidly became a common descriptive of malaria risk across Africa. During the 1960's, David Clyde published a series of historical data for Tanzania describing patterns of endemicity by region according to the parasite ratio(10). In Uganda, during the period 1959 to 1960, the WHO/Uganda Malaria Eradication Pilot Project (MEPP) mounted sample surveys of parasite prevalence across the country in preparation for the implementation of the Malaria Eradication Programme(11). Since these early descriptions, there have hardly been any attempts to compile malaria parasite prevalence survey data from East Africa in order to map malaria endemicity. This paper presents the results of a five-year data search and compilation of *P. falciparum* infection prevalence data.

MATERIALS AND METHODS

The feasibility of building a national database of published and unpublished parasitological data was established in Kenya during 1998(12). This led to the formation of a research network called the Mapping Malaria Risk in Africa (MARA) project(13). A data collection proforma was designed to capture a broad range of indices related to malaria risk. The proforma included a unique identifier for each data source and subsequent suffixes for other data from the same source. Parasite prevalence data were regarded as separate if the cross-sectional surveys were conducted at different times within the same report and/or different geographical areas. Care was taken to record as many details as possible on the study location and where maps were provided in the survey report, these were photocopied and attached to the data collection proforma for later determination of the longitude and latitude co-ordinates of the survey site.

Data searches: The data search strategy relied on multiple approaches to ensure a comprehensive coverage of all possible information. Electronic database searches were performed using Medline® (SilverPlatter International, Boston, MA, USA 2000), Popline® (Johns Hopkins School of Hygiene & Public Health, Baltimore, MD, USA) and EmBase® (Elsevier Science, Little Rock, Arkansas, USA 1999-2000). The following keywords were used in the search; malaria, Africa, East Africa, Kenya, Tanzania, Uganda, parasite and malaria and Africa, *Plasmodium falciparum*, parasite rate, parasite prevalence and malaria transmission. For each publication, bibliographies were cross-referenced to identify additional sources of information and other studies. Where additional details could not be identified through the literature searches authors were contacted to provide more information on geographical location, timing and age specific characteristics of their parasitological data.

Pre-electronic journals held at the Wellcome Library (located at the National Public Health Laboratories in the grounds of the Kenyatta National Hospital), archived collections at the London School of Hygiene and Tropical Medicine and at the University of Oxford were reviewed volume by volume systematically from the earliest volume available. In addition, national or regional, non-electronically referenced peer-reviewed journals were manually reviewed for additional data. Annual reports and unpublished reports from mission hospitals, drug companies and non-governmental organisations involved in health care delivery or research in each country were opportunistically accessed using local information on who had undertaken malaria surveys.

Postgraduate theses in the libraries of the University of Nairobi Medical and Chiromo Campuses and the Community Health Department (Kenya); Makerere University's Department of Child Health, Division of Public Health (Uganda); and Muhimbili University College of Health Sciences (Tanzania) were searched. Visits were also made to national institutes for medical research (Kenya Medical Research Institute, Nairobi; National Institute for Medical Research, Dar es Salaam) to identify published proceedings of national conferences, annual reports and institute journals. These were searched manually to locate additional parasite survey reports. Of particular note were the annual reports of the pre-1980 WHO-established centres of the East African Institute for Medical Research and the East African Community's East African Institute of Malaria and Vector-Borne Diseases whose headquarters were located at Amani, Tanzania .

Results of routine parasite prevalence surveys undertaken by Ministrys of Health in Kenya and Uganda were of special interest. In Kenya, the Division of Vector Borne Diseases (DVBD) has been involved in routine vector-borne disease surveillance activities, which include periodic parasite prevalence surveys of communities and schools, since its establishment in 1951. The reports of these surveys were available at the DVBD headquarters in Nairobi. In addition, a visit to six other provincial headquarters was made to identify additional material from 45 field stations operated by DVBD to locate information that may have not been forwarded to the headquarters in Nairobi. At the completion of the pre-eradication parasite prevalence surveys the office of the MEPP located in Jinja, Uganda, was closed and occupied by a paramedical training centre. While all project documents were removed (and largely destroyed), a few items of furniture including a small filing cabinet remained on site and unopened for many years. Fortunately, the raw data from the 1959-1960 eradication pilot project that focused on three districts in Uganda was found in this cabinet.

Spatial positioning of survey data: All parasite survey data were "geo-referenced" (i.e. their latitude and longitude coordinates determined). A limited number of reports provided geographical coordinates but for most survey reports only the survey site name was available. To identify the precise location of these sites, a variety of techniques and complimentary sources of information were applied. First, maps provided in the reports were used to begin the more thorough positioning of each survey. The next important source was topographic maps of varying resolution and detail; in particular, the 1:50000 scale maps produced by the Directorate of Overseas Surveys in 1971 for East Africa. Digital gazetteers(14,15) listing place names and their spatial co-ordinates were used for sites that were not recorded on

topographical maps. Finally, through correspondence with various research groups, particularly the International Livestock Research Institute (ILRI) and the United Nations Environmental Project (UNEP) Global Resources Information Database offices based in Kenya, various digital administrative unit boundary maps were obtained. These allowed an approximation of spatial positions for those that could not be spatially defined though the original source report, topographical maps or, electronic gazetteers.

Data entry: All the data were entered using a customised data-entry programme developed in Microsoft Access 97 (Microsoft Corporation, 1989-1996; Seattle, Washington USA). Data were entered twice by different data entry clerks and both files were verified against each other to detect data entry errors which were corrected subsequently using the original proformas. A programme was run to re-check consistency errors, for example inconsistencies in two date fields or district names for a given country. The main Access file served as the primary source for future data extractions. Data were later managed and analysed in Excel (Microsoft Excel version 9.0).

Data selection: Rigorous selection criteria were applied to the primary data. First data were combined from individual survey reports if repeat surveys were undertaken by the same investigators at the same location within a 24 month period or surveys undertaken by different investigators at different times in the exactly same location within a 24 month period. Surveys were spatially mapped using a Geographic Information System (GIS) software, MapInfo Professional Version 7.0 (MapInfo Corporation 1985-2000; Troy, New York) and this was used to select a single estimate for each spatial unit. Where two or more surveys were identified in the same location undertaken > 24 months apart or with different age classes, the most congruent age class survey was selected followed by a selection for surveys reporting the most detailed methodology, the largest sample and then lastly followed a criterion based on the most recent survey within two time-periods (<1980 and >=1980).

The surveys identified represented a variety of sampling approaches, including household-level random studies to non-random or purposively sampled households that may have included volunteers, surveys of healthy attendees at maternal and child health and expanded programme for immunisation clinics (MCH/EPI), surveys of school children and anti-malarial drug-resistance screening surveys. Surveys that might have been subject to sampling error introduced through selective recruitment were excluded and only studies that recruited children at the community level were included in the analysis. Those included comprised total population, randomly sampled or longitudinal community surveys.

Age ranges used during the parasitological surveys also varied between surveys. Where possible, survey data have been pooled to provide a single estimate within the age range of 0-15 years but surveys which included only children aged less than two years were excluded. Surveys were excluded if they covered age ranges above 15 years. Sample size is likely to affect the accuracy of the prevalence estimate and to control for this; only surveys where at least 50 subjects were sampled were included, based on proposed sampling strategies for parasitological surveys(16). Studies for which sample size details were unavailable were excluded.

The spatial extent of the surveys was also an important selection criterion. There were several studies that covered very wide spatial areas, for example >4th level administrative units. These posed a particular problem for the present analysis as the spatial extent of sampling within these polygons was unclear and thus it was also unclear how representative the parasitological data were of the administrative unit polygon. All reports covering areas larger than 4th level administrative units were therefore excluded for each country. Similarly, studies that could not be accurately positioned were excluded.

RESULTS

The data search identified 2003 *P. falciparum* prevalence surveys undertaken in East Africa since 1907. Eight hundred and fourteen were undertaken among patients attending maternal and child health or expanded programme for immunisation clinics, MCH/EPI, schools or participants of drug trials or intervention studies. These were excluded from the database. Thirty six additional surveys were excluded as they could not be spatially positioned due to a lack of sufficient detail on where they were undertaken or a lack of congruence with digital place names. A further 205 surveys were excluded because they were undertaken among samples of less than 50 subjects. Age ranges varied between surveys and surveys undertaken only among children aged less than two years (n=9) and surveys whose sample age range extended beyond 15 years (n=122) were also excluded. Finally a selection was made for single surveys where more than one survey had been undertaken in the same community >24 months apart, resulting in the exclusion of 161 "spatial duplicates' .

The reduced data set contained 503 prevalence surveys undertaken in Kenya (294), Tanzania (142) and Uganda (67) between 1927 and 2003, representing the examination of 202,628 children. Forty three percent, of the surveys were conducted before 1980. The frequency of parasite surveys undertaken within ten year time periods is shown in Table 1. We have chosen to divide this time period into two: 1927-1979 and 1980-2003 to provide a historical versus contemporary comparison of survey data in the sub-region being cognisant of major changes that have occurred in the emphasis of malaria control (vertical approaches to vector control pre-1980, to integrated disease control within general health services post-1980) and the emergence of drug resistance. The sources of the survey data, whether undertaken by Ministries of Health, sample sizes and age ranges of the surveys are summarised in Table 2. Ministries of Health were an important source of empirical data representing over 43% of all survey reports. This was particularly true of Kenya. In Uganda there seems to have been a decline in survey effort since 1979 compared to the earlier time periods, possibly reflecting the reduced planning efforts after the national MEPP and a lower malaria research output compared to Kenya and Tanzania. The age ranges and sample sizes included in the surveys did not vary significantly between the two time periods or between countries.

Table 1

Decade frequency of community-sampled surveys of P. falciparum infection prevalence in East Africa

Year of survey	Kenya	Tanzania	Uganda	Total
1920-1929	6	0	0	6
1930-1939	2	1	0	3
1940-1949	5	0	1	6
1950-1959	11	18	1	30
1960-1969	17	16	31	64
1970-1979	36	21	7	64
1980-1989	54	32	2	88
1990-1999	137	24	25	186
2000-2003	26	30	0	56
Total number of surveys	294	142	67	503

Table 2

Description of selected parasite prevalence surveys in East Africa

	Kenya	Tanzania	Uganda	Total
Total number of surveys identifed	992	522	489	2003
Excluded	698	380	422	1500
Characteristics of surveys 1927-1979				
Total number of surveys	77	56	40	173
Surveys reported in peer-reviewed journals	25	23	27	75
Surveys undertaken by Ministries of Health	50	13	0	63
Median interquartilerange of sample sizes	165(129;315)	311(170;617)	93(67;373)	191(112;432)
Surveys with age ranges within 0-5 years	0	9	18	27
Surveys with age ranges within 0-10 years	60	40	20	120
Surveys with age ranges within 0-15 years	17	7	2	26
Median IQR of parasite prevalence	40.6(20.6;56.4)	35(16.4;63.0)	49.3(17.9;71.8)	40.1(18.3;62.1)
Lower and upper prevalence recorded	1.5;86.7	0;87.3	0;87.5	0;87.5
Characteristics of surveys 1980-2003				
Total number of surveys	217	86	27	330
Surveys reported in peer-reviewed journals	11	24	7	42
Surveys undertaken by Ministries of Health	116	30	12	158
Median (interquartile range) of sample sizes	221(119;431)	194(146;443)	88(76;265)	204(120;427)
Surveys with age ranges within 0-5 years	32	61	0	93
Surveys with age ranges within 0-10 years	134	16	17	167
Surveys with age ranges within 0-15 years	51	9	10	70
Median (IQR) of parasite prevalence	33.7(14.3;54.0)	34.8(18.5;67.9)	47.5(28.3,79.5)	35.1(17.0,56.3)
Lower and upper prevalence recorded	0;94.5	0;96.1	6.7;90.6	0;96.1

Table 3

First-level administrative boundary median (IQR) (n) P. falciparum parasite prevalence survey data for Kenya, Tanzania and Uganda: 1927-1979 and 1981-2003

	1927-1979	1980-2003	Population*
Kenya			
Nairobi		16.7 (11)	2,143,254
Central		2.8(2.4,8.7) (17)	3,724,159
Coast	28.1 (8.3,37.0) (33)	34.0(26.3,54.1) (137)	2,487,264
Western	46.0 (1)	59.4(34.9,77.8) (14)	3,358,776
Nyanza	57.1 (47.9,70.2) (31)	49.2(32.1,59.7) (97)	4,392,196
North Eastern		7.3(5.4,12.1) (16)	962,143
Eastern	20.3 (9.0, 26.5) (7)	20.6(7.1,29.7) (35)	4,631,779
Rift Valley	35.4 (32.0,56.4) (5)	4.8(0.9,17.0) (10)	6,987,036
Tanzania			
Dodoma	10.1 (5.5,15.2)(5)	17.3(1().4,19.2)(7)	1,707,275
Arusha	26.2 (13.5,48.3) (3)	22.4(8.8,39.4)(10)	1,221,890
Kilimanjaro	38.6 (23.3,56.5)(20)	11.3(7.5,14.7)(7)	2,019,963
Tanga	53.8 (37.6,74.3) (11)	54.5(33.7,70.7) (22)	1,742,413
Morogoro	75.4 (73.8,80.8) (5)	85.6(43.6,88.4) (6)	1,783,664
Pwani	87.2 (1)	76.6(60.7,84.1) (4)	848,316
Dar es Salaam	33.9,34.0 (2)	19.7.48.5 (2)	2,547,217
Lindi		73.9 (1)	848,562
Mtwara	8.3 (1)	63.4 (50.9,75.4) (4)	1,079,816
Ruvuma			1,222,242
Iringa		44.1(12.1,75.6) (9)	1,737,791
Mbeya	4.4 (1)		2,235,271
Singida			1,109,005
Tabora	25.0 (24.0,55.0) (3)		1,432,673
Rukwa			1,218,977
Kigoma			1,240,939
Shinyanga			2,615,565
Kagera	20.0 (1)	24.2,36.4 (2)	1,957,921
Mwanza	52.2 (1)		2,665,956
Mara			1,432,476
Manyara			999,729
North Unguja		25.7,45.6 (2)	137,976
South Unguja		18.1 (1)	110,733
West Unguja/Urban	2.0 (1)	46.7 (1)	363,253
North Pemba	0 (1)	34.1(26.3,42.4) (4)	203,137
South Pemba		39.2 (34.7,45.5) (4)	188,695
Uganda			
Central	32.3 (26.9,56.1) (8)	32.0 (23.4,39.8) (8)	6,683,887
Eastern	16.7 (16.5,35.5) (3)	47.6 (39.6,77.2) (10)	6,301,677
Northern	56.6 (44.6,78.2)(17)	80.5 (79.9,82.8) (3)	5,345,964
Western	33.5 (1.3,72.2) (12)	54.9 (31.3,80.4) (6)	6,417,449

*Population data refer to the latest available national census. Kenya (1999: *http:/www.cbs.go.ke);* Tanzania (2002; *http:/www.tanzania.go.tz/census/census);* Uganda (2002: *http://www.ubos.org).*

National medians and inter quartile ranges of infection prevalence are shown in Table 2 for the two time periods. These ranges of infection prevalence simply serve to demonstrate the diversity of malaria endemicity covered by the surveys included in the database rather than as an indication of national infection risks. The latter is best considered at sub-national resolution. Table 2, however, suggests that surveys undertaken in Tanzania were conducted in areas of higher prevalence compared to surveyed areas in Kenya and Uganda. To examine the spatial and temporal differences in *P. falciparum* infection prevalence further, we have analysed survey data according to first level administrative units (Kenyan provinces, Tanzanian regions and Ugandan regions) using recent UN approved international country boundaries(17). The longitude and latitude co-ordinates of the centroid of each survey site was used to attribute each survey to one of eight administrative boundaries in Kenya, 26 in Tanzania and four in Uganda (Figures

1a and 1b). Comparison of Figure 1 a (1927-1979) with Figure lb (1980-2003) further highlights the decline over time in information for Tanzania and Uganda and also the changes in the spatial focus of survey work within countries that have occurred over-time. The studies undertaken pre-1980 are more widespread and so are more representative of the wide range of malaria ecologies experienced in the countries studied. Later studies have focused on specific ecological sites, notably low malaria risk highland areas in the Usambara Mountains of Tanzania and Kigezi in Uganda and some arid areas of northern Kenya as well as areas of more intense transmission along the Kenyan coast and the Lake Victoria Basin, likely to be a reflection of where research groups operate.

Figure 1a

The spatial distribution of P. falciparum parasite surveys undertaken between 1927 and 1979(•) against first-level UN approved administrative boundaries (17) for Kenya, Tanzania and Uganda

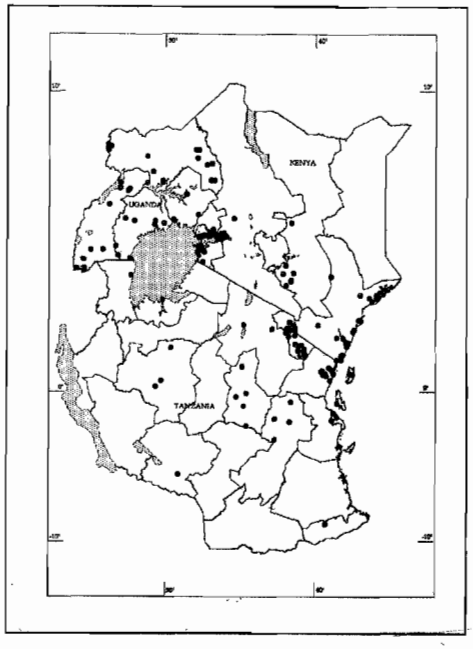
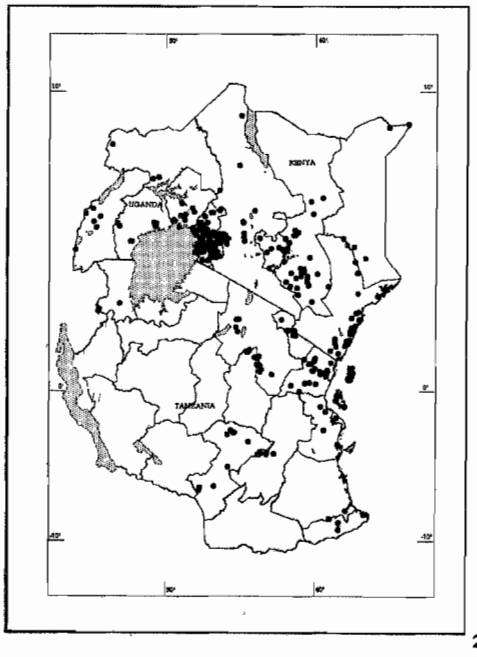


Figure 1b

The spatial distribution of P. falciparum parasite surveys undertaken between 1980 and 2003(•) against first-level UN approved administrative boundaries (17) for Kenya, Tanzania and Uganda



The number of surveys, median of the infection prevalence estimates and ranges of parasite prevalence by administrative unit between 1927-1979 and 1980-2003 are shown in Table 3. The first observation, as shown in Figures 1 a and 1 b, is that there is a paucity of information in several populated areas of East Africa, notably the south and west of Tanzania, the northern regions of Uganda and northern and central parts of Kenya. Secondly, there is a wide range of parasite prevalence estimates within a given administrative boundary, as shown by the interquartile ranges in Table 3 for areas such as Arusha and Tanga in Tanzania. This would be expected given the coarse spatial resolution of first-level administrative boundaries which, in some cases, cover up to 183,000 km^2 (Rift Valley Province in Kenya) thus encompass a diverse range of altitude and ecology. Nevertheless areas reporting low parasite prevalence tend to be those located either at high altitude (highlands of Tanzania) or arid areas (North Eastern and areas north of Eastern Province in Kenya) and thus conform to our basic understanding of malaria transmission in the sub-region.

DISCUSSION

The Roll Back Malaria (RBM) initiative is a global partnership of donor agencies, Ministries of Health, the private sector and non-Governmental Organisations in malaria endemic countries(3). The overall objective of RBM is to halve the global burden of malaria by the year 2010 through sustained and multi-pronged intervention strategies(3). Equal optimism was expressed during the early part of the last century with the World Health Organisation's 8th World Health Assembly adoption of a Global Malaria Eradication Campaign in 1955 and the expansion of effective drugs for disease management and residual house-spraying(18). Today, strategies for malaria control include; prompt access to effective treatment, access to Insecticide Treated Nets (ITNs), prevention and control of malaria during pregnancy through intermittent presumptive treatment and effective response to epidemics and emergencies(3). Today's emphasis is on the development of interventions that are adopted to local needs and supportive of the health sector development strategy adopted by governments in several sub-Saharan African countries. A key failure of the malaria eradication era in the tropics and sub-tropics was the lack of recognition of the geographical differences in the epidemiology of malaria and in vector behaviour(19). The WHO strategy in the 1950's assumed that a uniform eradication approach would be effective over a wide range of malaria ecologies and the importance of these differences was only recognised in hindsight.

Current control approaches require a renewed examination of the geographical determinants of malaria. Maps of malaria risk are pivotal to the achievement of a spatial dimension to planning malaria control activities. Several historical maps do exist of malaria risk in East Africa(20-22), however these were developed from "expert opinion" during the late 1950's and early 1960's. These maps were not based upon empirical data and it seems reasonable to assume that risks have changed over the last fifty years. The present review demonstrates two things: firstly, there are data available but often these are not consolidated into centralised databases for public domain access. The collation of the data presented in this study has taken five years and it is the intention of the authors to host the empirical data on an appropriate website. The second important observation is that the contemporary survey data that are available are concentrated in areas where malaria research groups work. This differs from earlier work, before 1980 that aimed to provide national survey data in countries such as Tanzania and Uganda. The limited spatial coverage of survey data prevents easy extrapolation to distant areas that might have very different ecological characteristics lending themselves to very different transmission patterns. There has been a renaissance in malaria mapping and recent advances in disease mapping using Geographic Information Systems (GIS) coupled with an increased access to improved geo-referenced databases on correlates of malaria transmission have rekindled an interest in such epidemiological investigations(23). In particular, the relationship between climate and vector-borne disease transmission has been exploited in mapping the distribution of these diseases(24-25). Currently available climate-based maps are limited in that they consider only a few of the multiple factors that determine malaria's transmission omitting key covariates such as urbanisation, land use and the effects of malaria control interventions (24,26-28).

New spatial models of malaria risk require a source of empirical spatially referenced data for their construction and validation. The data presented in this paper represent one of the largest survey collections for the sub-region and will be used to develop improved, high-resolution models of malaria risk. Such maps should form the basis of decision-making for control interventions; definition of target populations for these interventions and estimation of resource needs within the sub-region. A better geographical awareness of risk will hopefully result in improved use of limited resources available towards achieving RBM goals in East Africa.

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