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The influence of urbanisation on measures of *Plasmodium falciparum* infection prevalence in East Africa

J.A. Omumbo^{a,*}, C.A. Guerra^b, S.I. Hay^{a,b}, and R.W. Snow^{a,c}

^aPublic Health Group, KEMRI/Wellcome Trust Research Programme, P.O. Box 43640, 00100 GPO, Nairobi, Kenya

^bDepartment of Zoology, TALA Research Group, Tinbergen Building, University of Oxford, South Parks Road, Oxford, UK

^cCentre for Tropical Medicine, John Radcliffe Hospital, University of Oxford, Oxford, UK

Abstract

There is a growing interest in the effects of urbanisation in Africa on *Plasmodium falciparum* risks and disease outcomes. We undertook a review of published and unpublished literature to identify parasite survey data from communities in East Africa. Data were selected to represent the most reliable and contemporary estimates of infection prevalence and were categorised by urban or rural status using a number of approaches. We identified 329 spatially distinct surveys undertaken since 1980 in the sub-region of which 37 were undertaken in urban settlements and 292 in rural settlements. Overall rural settlements reported significantly higher parasite prevalence among children aged 0–14 than urban settlements (on average 10% higher infection rates; $p < 0.05$). No urban settlements recorded parasite prevalence in excess of 75%. In areas of East Africa where climatic conditions are likely to support higher parasite transmission, the rural–urban difference was most marked. There was a significant trend towards documenting higher classes of parasite prevalence in rural compared to urban settlements ($p < 0.05$) and the mean difference between rural and urban samples was 18% ($p < 0.001$). These results further highlight the need to better define urban extents in Africa in order to capture the non-climatic determinants of infection and disease risk and provide a more informed approach to describing the burden of disease across the continent.

Keywords

Malaria; Urbanisation; Disease burden; *Plasmodium falciparum* prevalence; East Africa; GIS; Maps

1. Introduction

The majority of the Disability-Adjusted Life Years (DALY) for sub-Saharan Africa (SSA) is driven by high mortality in early childhood from infectious diseases (diarrhoeal and respiratory diseases, measles and malaria) and high mortality in young adults from HIV infection and tuberculosis (Murray and Lopez, 1997; World Health Organization, 2002). The DALY approach to prioritising disease intervention has led to improved efforts to define disease-specific mortality rates. Despite the paucity of data, pan-African extrapolations of specialized survey data on acute respiratory tract infections (Williams et

al., 2002), HIV (Walker et al., 2002) and malaria (Snow et al., 1999; Snow and Omumbo, 2004) have been used to re-estimate the contribution made by these infectious diseases to the mortality burden in SSA. Only the estimations for malaria have allowed for the spatial determinants of populations-at-risk of infection and their effect upon subsequent disease risks.

At the population level, the chances and frequency of *Plasmodium falciparum* infection risk influence age-specific disease outcomes: low infection risks result in lower malaria mortality rates and are not influenced by acquired immunity; increasing intensities of transmission support increasing mortality risks and are markedly influenced by age-specific acquired immunity (Snow and Marsh, 2002). The transmission patterns of *P. falciparum* in Africa vary between countries, and more importantly for disease burden estimation, within national borders. The estimates of the malaria burden in Africa have used populations-at-risk of different climate-determined patterns of transmission to reflect the spatial heterogeneity of infection risk on disease outcome (Craig et al., 1999; Snow et al., 1998; Snow and Omumbo, 2004).

One important caveat to this approach has been the inability of the current continental-scale malaria risk maps to reflect other influences upon transmission, notably urbanisation. Two recent reviews suggest that urban populations in Africa receive, on average, 10 times fewer new infections from vectors compared with their rural counterparts (Hay et al., 2000; Robert et al., 2003). In 2000, 38% of Africa's 784 million inhabitants were urban dwellers and this is expected to increase to 55% by 2030 (United Nations, 2002). This shift in human populations from environments supporting predominantly communicable disease burdens to those lending themselves to non-communicable diseases will have profound epidemiological and public health impacts (Harpham, 1997). In this paper we examine differences in *P. falciparum* prevalence between urban and rural settlements of East Africa to explore the likely impact of urbanisation on malaria burdens in this sub-region.

2. Material and methods

2.1. *P. falciparum* prevalence survey data among children aged 0–15 years in East Africa

A search was conducted of published and unpublished literature related to malaria infection prevalence surveys in the East Africa region. Electronic database searches were performed using Medline® (SilverPlatter International, Boston, MA, USA, 2000), Popline® (Johns Hopkins School of Hygiene and Public Health, Baltimore, MD, USA, 2000) and EmBase® (Elsevier Science, Little Rock, AR, USA, 1999–2000). The following keywords were used in the search: malaria, parasite and malaria and Kenya, Tanzania, Uganda, *P. 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 published sources, authors were contacted to provide more information on geographical location, survey dates and age-specific characteristics of the parasitological data. Postgraduate theses held in the libraries of Nairobi, Makerere and Muhimbili Universities were also searched. Annual reports, journals and conference proceedings of national medical research institutes, and non-governmental organisations were reviewed in each country. Results of routine parasite prevalence surveys undertaken by the Ministry of Health's (MoH) Vector or Malaria Control Departments in Kenya and Uganda were manually searched during field visits to archives at headquarters in each country, and in Kenya at provincial offices.

Using a variety of sources: 1:50,000 scale topographic maps (Directorate of Overseas Surveys, 1971), digital maps of administrative units in Kenya (Central Bureau of Statistics, 1989) or public domain digital gazetteers (GDE Systems, GeoName, 1995; World Resources

Institute, Africa Data Sampler, 1995), a longitude and latitude was ascertained for each parasitological survey in decimal degrees. This centroid served as a unique identifier for each survey and, combined with a description of the survey, was used to describe the spatial extent of each sample. Surveys were classified as representing one of five spatial dimensions. First, surveys representing a single village where the central longitude and latitude was used to define point estimates covering the community using ArcView 3.2 (ESRI, Redlands, CA, USA). The second spatial classification reflected surveys that sampled from several villages but presented the data as a single parasite ratio (five and seven surveys in Kenya and Tanzania, respectively). In this case, a polygon was created to connect the villages. The third, fourth and fifth spatial criteria corresponded to surveys undertaken at the fifth (sublocation: average area covered 9.4 km²), fourth (location: average area covered 15.4 km²) or third (division: average area covered 34.1 km² administrative levels in Kenya (Hay et al., in press).

All surveys undertaken in Kenya, Tanzania and Uganda ($n = 2003$) were subjected to a number of selection criteria for inclusion in the present analysis (Table 1). The selection allowed for contemporary assessments of infection risk (>1979); inclusion of community-based surveys; age ranges within 0–15 years (excluding surveys where only infants sampled); minimum sample sizes of 50 children; and adequate details on location, and denominators. Finally, repeat surveys by the same investigators within a 24-month period were combined to a single estimate and surveys undertaken by several investigators at different times in the same location were reduced to one estimate by excluding either the earlier survey or smaller sample size.

2.2. Defining urban and rural extents

Urbanisation is a difficult demographic concept to define and there are inconsistencies between international, national and published definitions (Vlahov and Galea, 2002; Tatem and Hay, in press). We have used a combination of approaches to classify urban surveys. First we accepted the investigators urban/rural description as stated in the survey reports. Second, we used the name of the survey site to validate the descriptions, e.g., if a study site was reported as “Malindi town”. Third, we compared national census bureau administrative boundaries (Central Bureau of Statistics, Kenya, 1989; Statistics Department Uganda, 1995; Bureau of Statistics, Tanzania, 2002) of known urban extents against the spatial position of each survey to identify those whose survey report or community name did not provide adequate information to classify them as urban or rural. Here we classified urban settlements if they were located in national census bureau definitions of cities, towns or market centres.

Finally we used a global database of urban extents developed as part of the Global Rural–Urban Mapping Project (GRUMP) (Balk et al., 2004; CIESIN/CIAT, 2004; CIESIN/IPFRI/CIAT, 2004). The urban mask was developed at a 1 km × 1 km spatial resolution using data on night time lights (Sutton et al., 2001) and Landsat satellite imagery in combination with other geographic data (Digital Chart of the World populated places (Mika, 1997), Tactical Pilotage Charts produced from Australian Defence Imagery and Geo-Spatial Organisation, and national census data). The spatially distinct polygons or points for each parasite prevalence survey were created using a digital administrative map of Kenya (CBS, 1989), first warped to UN approved national boundaries (SALB, 2004) using ArcView 3.2 (ESRI, Redlands, CA, USA). The GRUMP urban extents were mapped to the single longitudes or latitudes or polygons of each the parasite surveys using ArcView 3.2 (ESRI, Redlands, CA, USA). For surveys covering wider areas (clusters of communities or third–fifth level administrative units), the percentage of the polygon covered by urban extents was extracted using the MILA Utilities 3.2 update extension within ArcView 3.2 (<http://www.esri.com/>

[arcscrip](#)ts). If more than 75% of the polygon was classified as either urban or rural the survey was classified accordingly.

2.3. Malaria ecological zonation of East Africa

To compare urban–rural differences in parasite prevalence within broad, climate-derived malaria risk classes we have used an 8 km × 8 km resolution malaria risk map developed to approximate to the historical descriptions of malaria transmission in East Africa (Omumbo et al., 2002). In brief, Fourier processed data from remotely sensed images related to land surface temperature (LST), rainfall and moisture availability as inferred by cold cloud duration (CCD), and normalised difference vegetation index (NDVI) data were used to construct a model of malaria risk. Discriminant analysis of the models ability to predict the historical categorization of four malaria risk zones in Kenya, Tanzania and Uganda showed that malaria free areas could be predicted with a 96% accuracy, while areas where transmission occurs only near water, moderate malaria areas and intense malaria transmission areas were predicted with accuracies of 90, 72 and 87%, respectively. For the purposes of the present analysis we have grouped the malaria risk areas: malaria free with malaria only near water and moderate with intense transmission areas to distinguish between low and moderate-to-high infection risks (Fig. 1).

Parasite survey data were classified in accordance with the two malaria ecozones based on the polygon spatial extents of each survey (Table 3) with a 2.5 km buffer (approximating to the average flight distances of *Anopheles gambiae s.l.* (Service, 1997)) using ArcView 3.2 (ESRI, Redlands, CA, USA). Parasite survey data were classified as only one ecozone category where more than 75% of the surface area was dominated by that zone class.

2.4. Data entry and statistical methods

All parasite survey data were recorded on standard proformas and entered twice in Microsoft® Access version 7 (Microsoft Corporation 1989–1996; Seattle, WA, USA). Data entry errors and range inconsistencies were checked and verified against original material. Data were extracted for matching to other data sources using Microsoft® Excel 2000 version 9.0. Data were analysed using SPSS for Windows Release 10.01 (SPSS, 1999, Chicago, IL, USA). Mean differences between urban and rural survey reports of parasite prevalence were tested using analysis of variance (ANOVA) and categorical descriptions of the ranges of parasite prevalence between urban and rural settlements were tested using a chi-square for trend.

3. Results

A total of 330 spatially independent parasite surveys were identified that met the selection criteria across East Africa. The exclusions and characteristics of these surveys are shown in Tables 1 and 2. The surveys in the three countries were distributed across the two principal malaria ecological zones as shown in Fig. 1 and Table 3. The step-wise classification of urban/rural settlements left one survey sufficiently ambiguous at the final classification stage and was excluded from subsequent analysis. Three hundred twenty-nine surveys were included in the final analysis comprising 37 urban and 292 rural surveys. Almost all urban settlements were adequately described within the survey reports, survey site name or national census bureau definitions of urban settlements ($n = 28$). GRUMP identified a further nine areas that were ambiguous from the survey reports and were not defined in the national census bureau urban centres. However, we were struck by omissions, within GRUMP, of obvious urban settlements ($n = 15$) (e.g., within the city limits of Mombasa, large towns such as Zanzibar, Kilifi and Malindi and market centres in Busia and Ifakara). Thus, using a combined series of approaches to defining urban settlements was deemed an

appropriate strategy and highlights the continued lack of comprehensive coverages of urban settlements in the sub-region.

A comparison of the mean parasite prevalence in urban and rural settlements demonstrated that rural surveys reported on average a 10% higher prevalence of infection in childhood compared to urban surveys (Table 4: ANOVA, F statistic = 5.37, $p = 0.021$). This difference persisted when rural and urban surveys were compared between areas of low malaria risk (8% lower in urban areas) and areas of moderate-to-high malaria risk (18% lower in urban areas) (Table 4). Only the rural–urban differences in the ecologically classified areas of moderate-to-high transmission, however, were statistically different (ANOVA, F statistic = 11.06, $p = 0.001$). The median and interquartile ranges of the overall and malaria ecozone urban and rural samples are shown in Fig. 2.

Table 4 also shows the comparison of the categorical ranges of parasite prevalence reported by surveys undertaken in rural and urban areas. No surveys undertaken in urban settlements reported parasite prevalence in excess of 75%. Overall the trend toward describing higher parasite prevalence (25–74% or 75%) in rural (192/292, 65.8%) compared to urban (23/37, 62.2%) settlements was not significant ($\chi^2 = 5.48$, d.f. = 2, $p = 0.065$). Comparison of urban–rural parasite distributions in areas of low transmission was not possible due to the small numbers of samples in this category. However, in moderate-to-high transmission malaria risk areas the difference between rural (161/208, 77.4%) and urban (22/32, 68.8%) reporting higher parasite prevalence was significantly different ($\chi^2 = 6.37$, d.f. = 2, $p = 0.041$).

4. Discussion

We have set out to examine the differences in *P. falciparum* infection prevalence among rural and urban children sampled as part of parasitological descriptions of malaria endemicity in East Africa. We have applied rigorous selection criteria to the data identified through an exhaustive search of the literature (Table 1). We believe that reviews of previously published or unpublished literature should apply strict selection criteria to ensure comparability in the data being analysed. It is important to note that our final sample of surveys was, by definition, not a spatially random series of surveys and subsequent analysis will always be limited by where the majority of data derive. The filtering and attribution of surveys to urban or rural classifications resulted in only 37 surveys undertaken in urban areas compared to 292 in rural areas. The limited information from urban settlements probably reflects the general consensus that malaria is a rural problem and epidemiologists often focus their investigations on these communities. Nevertheless, for those surveys identified, among childhood populations in East Africa there were significant differences in the parasite prevalence estimates reported for rural and urban settlements. Overall rural settlements reported 10% higher parasite prevalence compared to urban communities and this difference was larger (18%) between rural and urban communities located in moderate-to-high malaria ecological risk areas of East Africa (Table 4; Fig. 2).

These findings are consistent with microepidemiological studies of urban malaria across Africa: decreasing risks of infection associated with urbanisation, either entomological or parasitological, have been shown in urban areas in West Africa: Liberia (Björkman et al., 1985), The Gambia (Lindsay et al., 1990), Senegal (Trape et al., 1992), Ghana (Gardiner et al., 1984), Burkina Faso (Robert et al., 1986; Rossi et al., 1986; Benasseni et al., 1987; Modiano et al., 1999); Central Africa: Cameroon (Fondjo et al., 1992), Republic of Congo (Trape and Zoulani, 1987), Democratic Republic of Congo (Ngimbi et al., 1982; Coene, 1993); the Horn of Africa: Ethiopia (Yohannes and Petros, 1996), Sudan (El Sayed et al., 2000); and Southern Africa: Zambia (Watts et al., 1990). Moreover, in a recent meta-

analysis of 159 sites across Africa where annual entomological inoculations rates (EIR) had been recorded, it was shown that people in rural areas received on average 146 *P. falciparum* infected bites per annum compared to only 14 for people resident in urban areas (Hay et al., 2000).

Recent years have seen a satellite imagery-fuelled renaissance in attempts to produce risk-maps of vector-borne diseases including malaria (Hay, 2000). To a large extent, both historical and contemporary malaria mapping have focussed on extrinsic climatic determinants of disease distribution (Craig et al., 1999; Rogers et al., 2002), ignoring other spatial determinants of malaria risk, most notably the effects of urbanisation. This is primarily because these parameters have been harder to define at the coarse spatial resolution of the climate data currently used to model malaria risk. This is likely to influence the estimation of disease burden. The risks of all-cause childhood mortality are substantially and consistently lower in urban compared to rural areas of Africa (MEASURE, 2004). Our results and those of others have consistently shown malaria infection risks are lower in urban settings compared to rural settings. Severe malaria morbidity (Snow et al., 1997), malaria mortality (Snow and Marsh, 1995) and all-cause mortality (Snow and Marsh, 2002; Snow and Omumbo, 2004) are all substantially lower in areas of low parasite prevalence (childhood infection prevalence less than 25%) compared to areas of higher stable endemicity in Africa. In addition to the biological constraints on infection risk, urban communities are more likely to have either the financial means or better access to measures which further reduce the risks of infection, such as insecticide treated nets (Holtz et al., 2002; Mugisha and Arinawe, 2003), intermittent presumptive treatment during pregnancy (Guyatt et al., 2004), or better malaria case-management and antimalarial treatment (Rasheed et al., 2000; Molyneux et al., 1999).

The categorical descriptions of endemicity using the parasite prevalence in our analysis of previously published surveys demonstrated that no urban settlements were able to support an infection prevalence in excess of 75% and that there was a significant difference in areas with a climate suitable for stable, endemic, transmission between urban and rural settlements supporting parasite prevalence ratios in excess of 25%. In Kenya, Tanzania and Uganda, approximately 28% of the population reside in urban settlements (UN, 2002) and it seems reasonable to assume therefore that in this sub-region a significant proportion of the population will be misclassified in terms of infection and subsequent disease risk on the basis of climate-driven cartography of risk alone.

For the first time spatially explicit estimates of population living in urban and rural environments are becoming available in the public domain. These surfaces have been implemented at global scales (Schneider et al., 2003; Balk et al., 2004; Tatem et al., in press). While these resources open significant new possibilities for exploring the impact of urbanization on malaria transmission over large areas, an important step in testing and validating their precision locally is needed as evidenced by discrepancies noted in our urban classification of parasitological survey data. This is warranted due to the novelty of these digital themes and the various techniques used to designate urban and rural land-use classes both as input training data (Tatem and Hay, in press) and output map products (Tatem et al., in press). These precision estimates for Kenya, Tanzania and Uganda are the subject of ongoing research, including the use of higher spatial resolution optical and synthetic aperture radar (SAR) satellite imagery. New, higher resolution, better-defined spatial descriptions of urban settlements will ultimately improve our continental scale estimation of malaria risk and disease burden.

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Fig. 1. Distribution of parasite prevalence surveys by malaria ecological zone in East Africa. Malaria-free or transmission occurring only near water (light grey), and moderate to high transmission areas (dark grey). Parasite prevalence survey sites included in the analysis are shown as black circles.

Fig. 2. Distribution of parasite prevalence data from 329 surveys in East Africa according to rural (R) vs. urban (U) classification in low and moderate-intense malaria risk areas and overall. Outliers (open circles) are cases with values between 1.5 and 3 box lengths from the upper edge of the box. The box length is the interquartile range and the line within the box represents the median.

Table 1
Selection criteria for parasite prevalence survey data in East Africa and description of selected surveys

	Kenya	Tanzania	Uganda	Total
Total number of surveys identified	992	522	489	2003
Exclusion criteria				
Excluded pre-1980	236	194	237	667
Excluded because unable to locate longitude/latitude	0	33	2	35
Excluded because no information on denominator	9	1	13	23
Excluded sample size <50	82	9	69	160
Excluded because non-community sampled ^a	408	128	121	657
Excluded sample age groups 0–15 or infants only	20	39	19	78
Excluded because spatial overlap with more contemporary or larger sample size survey ^b	20	32	1	53
Characteristics of surveys				
Final survey samples included in analysis	217	86	27	330
Surveys reported in peer-reviewed journals	11	24	7	42
Surveys reported in reports of Ministry of Health, NGO or donor reports	168	34	17	219
Surveys reporting total population sampling, longitudinal sampling, random sampling ^c	143	86	16	245
Surveys covering period 1980–1989	54	32	2	88
Surveys covering period 1990–1994	100	14	14	128
Surveys covering period 1995–2003	63	40	11	114
Median (interquartile range) of sample sizes	221 (119, 431)	194 (146, 443)	88 (76, 265)	204 (120, 427)
Surveys covering age ranges within 0–5 years ^d	32	61	0	93
Surveys covering age ranges within 0–10 years ^d	134	16	17	167
Surveys covering age ranges within 0–15 years ^d	51	9	10	70

^aSeveral surveys reported follow-up of patients during drug resistance surveys, or patients sampled during routine EPI/MCH clinic visits. These were excluded on the basis that it was difficult to know whether they represented community-based infection prevalence. In addition surveys conducted during randomized controlled trials of interventions were only included for control populations, intervention arms were excluded.

^bFor surveys which were contiguous with others, the most recent, largest sample size and most detailed in its reporting of sampling strategy was included.

^cSeveral surveys, particularly those reported by Vector Control or Malaria Divisions of the Ministry of Health, did not provide adequate sampling strategy details (26.4% ($n = 88$) of the overall survey samples). It is unclear whether these prevalence estimates have the same precision as surveys providing detailed descriptions of sampling and survey method.

^dThe surveys included in the analysis were not all consistent with a single age range. The surveys varied in the age groups sampled, e.g. 0–4, 1–4, 0–3, 0–9, 1–9, 1–12, 0–15, etc. The table represents the summary of three broad age classes using the upper age range as the defining age for sub-groups. Separate analyses have shown that the categorical description of endemicity based on the parasite ratio does not alter significantly within one area by different age groupings within the 0–15 years age range (Omumbo et al., in preparation).

Table 2

Spatial resolution of 329 *P. falciparum* parasitological surveys among children in Kenya, Uganda and Tanzania

Description	Kenya	Uganda	Tanzania
Village/community ^a	85	27	79
Cluster of villages/communities	5	0	7
Sub-location	112	0	0
Location	7	0	0
Division	8	0	0
Surveys in sub-locations, locations, divisions excluded as urban/rural extent could not be classified	1	0	0
Total sample included in analysis	216	27	86

^aEight studies in Uganda and five studies in Zanzibar/Pemba were recorded as villages or single communities where data were presented at sub-fifth level administrative boundary extents but covered dispersed areas.

Table 3

Malaria ecozone (Omumbo et al., 2002) classification for 329 independent parasite survey data in East Africa according to urban and rural coverage

Ecozone	Kenya (216)		Uganda (27)		Tanzania (86)		Total	
	Rural	Urban	Rural	Urban	Rural	Urban	Rural	Urban
Malaria free or only near water	58	4	7	0	19	1	84	5
Moderate-to-intense transmission	137	17	11	9	60	6	208	32
Total	195	21	18	9	79	7	292	37

Table 4

The mean, (95% CI) percentage parasite prevalence and distribution of infection prevalence^a between rural and urban surveys undertaken in two malaria ecological zones in East Africa

	Rural	Urban
Overall mean (95% CI) parasite prevalence	39.5 (36.4–42.6)	29.0 (23.9–34.1) ^b
Low malaria risk areas, mean (95% CI) parasite prevalence	22.2 (17.3–27.1)	14.5 (6.7–22.3)
Moderate-to-high transmission areas, mean (95% CI) parasite prevalence	46.5 (43.1–49.9)	31.3 (25.6–37.0) ^c
Overall number (%) surveys reporting prevalence <25%	100 (34.2%)	14 (37.8%)
Overall number (%) surveys reporting prevalence 25% to <75%	154 (52.7%)	23 (62.2%)
Overall number (%) surveys reporting prevalence 75%	38 (13.0%)	0 (0.0%)
Moderate-to-high transmission areas, number (%) surveys reporting prevalence <25%	47 (22.6%)	10 (31.3%) ^b
Moderate-to-high transmission areas, number (%) surveys reporting prevalence 25% to <75%	127 (61.1%)	22 (68.8%)
Moderate-to-high transmission areas, number (%) surveys reporting prevalence 75%	34 (16.4%)	0 (0.0%)

^aThe distribution of infection prevalence within low malaria risk areas is not shown, as there were only five urban surveys in this malaria risk class.

^bANOVA comparison of means between urban and rural samples *p* value < 0.05.

^cChi-square test comparison between urban and rural samples differences in prevalence criteria *p* value < 0.05.