Urban agriculture and operational mosquito larvae control: mitigating malaria risk in Dar es Salaam, Tanzania

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LIST OF ABBREVIATIONS

ACT	Artemisinin-based combination therapy
BTI	*Bacillus thuringiensis* var. *israelensis* (biological larvicide)
CDC	Centers for Disease Control and Prevention
CG	Corn granules
CGIAR	Consultative Group on International Agriculture Research
CMCC	City Mosquito Control Coordinator
CMSO	City Mosquito Surveillance Officer
CORP	Community-based resource person
DDT	Dichloro-Diphenyl-Trichloroethane (synthetic pesticide)
DfID	Department for International Development, United Kingdom
DUHP	Dar es Salaam Urban Health Project
EIR	Entomological inoculation rate
FAO	United Nations Food and Agriculture Organisation
GEE	Generalized estimating equations
GIS	Geographical Information System
GPS	Global Positioning System
GTZ	German Technical Cooperation
IDRC	International Development Research Centre
IEC	Information, Education and Communication
IFPRI	International Food Policy Research Institute
IHI	Ifakara Health Institute
IPG	Institute of Physical Geography, University of Freiburg
IRS	Indoor residual spraying (of insecticides)
ITC	International Institute for Geo-Information Science & Earth Observation
ITN	Insecticide-treated net
IVM	Integrated Vector Management
IWMI	International Water Management Institute
JICA	Japan International Cooperation Agency
LLIN	Long-lasting insecticidal net
M&E	Monitoring and Evaluation
MDG	Millennium Development Goal
MMCC	Municipal Mosquito Control Coordinator
MMCI	Municipal Mosquito Control Inspector

NCCR	Swiss National Centre of Competence in Research
NGO	Non-Governmental Organisation
NIMR	National Institute of Medical Research in Tanzania
NMCP	National Malaria Control Programme
RBM	Roll Back Malaria Partnership
RUAF	Resource Centres on Urban Agriculture and Food Security
SSA	Sub-Saharan Africa
TCU	Ten-Cell-Unit
TP	Transversal Package
UA	Urban agriculture
UMCP	Urban Malaria Control Programme
UNDP	United Nations Development Programme
UNFPA	United Nations Population Fund
UNICEF	United Nations Children's Fund
UPA	Urban and periurban agriculture
WCED	World Commission on Environment and Development
WDG	Water-dispersible granules
WHO	World Health Organisation
WMO	World Meteorological Organization
WRI	World Resources Institute

SUMMARY

Global commitment, political will and financial support to reduce the burden of malaria, a disease which kills about one million people each year, have reached an unprecedented level. Although global malaria eradication appears to be a distant goal, there are promising efforts towards regional control and local elimination of the disease.

Sub-Saharan Africa (SSA) is the region with the world's highest malaria burden, as well as the world's fastest growing cities. Rapid urbanisation brings enormous challenges such as increasing poverty and malnutrition, the spread of informal settlements, inadequate sanitation and lack of access to safe water, as well as health risks. Malaria transmission in urban settings, although to a lesser extent than in rural areas, remains a significant problem.

In Tanzania and many other developing countries, one response to increasing urban demand for food is urban agriculture (UA), especially in backyard gardens and larger open spaces. While urban farming is an integral part of livelihoods and food security, it may also increase the risk of vector-borne diseases, including malaria, by providing suitable grounds for mosquito breeding. However, it is unclear whether agricultural land use or rather geographical factors such as topography and hydrology lead to the creation of habitats for malaria vector mosquitoes.

The overall aim of this study was to contribute to a better understanding of the importance of urban agricultural land use in the context of environmental malaria control in urban SSA, and identifying potential mitigation options. All field research for this study was conducted in 2005 and 2006 in the city of Dar es Salaam, Tanzania, and was fully integrated in the operational Urban Malaria Control Programme (UMCP), managed by the Dar es Salaam City Medical Office of Health. The main goal of the UMCP is to control mosquito larvae with the application of biological larvicides by community-based resource persons.

The transdisciplinary research approach used in this study was a combination of natural and social scientific approaches, and took account of the knowledge and capacities of stakeholders in the context of the UMCP. Quantitative methods included participatory mapping of administrative boundaries, cross-sectional mapping of agricultural areas, and surveys of farmer's agricultural practices. Qualitative methods consisted of semi-structured key informant interviews and Focus Group Discussions using interview guidelines.

The theoretical framework that guided the study design and data analysis was based on the concepts of *risk*, *resilience* and *threat*, where risk is seen as a function of threat and resilience. In order to gain a more comprehensive understanding of factors related to malaria *risk* (*i.e.* malaria infection and disease), aspects of malaria *threat* (*i.e.* presence of breeding sites with potentially malaria-transmitting *Anopheles* mosquitoes) and *resilience* to malaria (*i.e.* social resilience in terms of increased competence of stakeholders in the context of the UMCP) were investigated.

In a first step, the current extent and characteristics of urban agriculture were assessed. This revealed that UA is widespread in Dar es Salaam, with more than 5% of the study area used for farming in 2005. Extrapolated to the total urban area, this corresponds to almost 20 km^2 of land used for urban agriculture in Dar es Salaam. Furthermore, an analysis of the spatio-temporal changes of urban agricultural use showed that urban farming is a dynamic, but not a short-lived or transitional phenomenon. The overall extent of UA did not decrease during the last two decades, despite the city's rapid growth and densification. UA thus appears to be resilient in terms of its ability to persist in the presence of high non-agricultural pressure on land use, and its ability to recover after disturbances by spatial shifts.

In a second step, a participatory mapping method was developed that allowed linking the agricultural data from 2005 with mosquito larval data from the UMCP. This was necessary in order to assess correlations of these agricultural areas with *Anopheles* breeding sites. At the same time, this procedure facilitated comprehensive routine larval surveillance by the UMCP. The approach involved basic use of aerial imagery and Geographical Information Systems (GIS), and was validated by mapping three urban wards of Dar es Salaam, covering an area of 16.8 km^2. The procedure enabled verification and correction of cognitive sketch maps drawn by UMCP field staff as guidance for their work, and therefore complete coverage of targeted areas with larval control. It proved to be practical, affordable, and requires minimal technical skill. Thus, it can be readily integrated into malaria vector control programmes, scaled up, and adapted to urban settings elsewhere in Africa. In Dar es Salaam, the participatory mapping approach became an integral part of the novel management, monitoring and evaluation system for implementing routine larviciding developed by the UMCP. Therefore, it partly contributed to the reduction of malaria transmission by the primary vector, *Anopheles gambiae s.l.*, by 31% (95% CI=21.6-37.6%; p=0.04).

In a third step, the agricultural data was linked with the UMCP larval database. This revealed that the proportion of habitats containing *Anopheles* larvae was 1.7 times higher in agricultural areas compared to other areas (95% CI: 1.56-1.92). Significant geographic predictors of the presence of *Anopheles* larvae in gardens included location in lowland areas, proximity to rivers, and relatively impermeable soils. Significant agricultural predictors comprised specific seedbed types, mid-sized gardens, irrigation by wells, and cultivation of sugar cane or leafy vegetables. Significant negative predictors included small garden size, irrigation by tap water, rainfed production, and cultivation of leguminous crops or fruit trees. Although there was an increased risk of finding *Anopheles* larvae in agricultural sites, breeding sites in urban agriculture accounted for less than a fifth of all breeding sites of malaria vectors in Dar es Salaam. The identified indicators of relatively high and low odds of larval presence in agricultural areas can help improve the effectiveness of larviciding interventions.

In a last step, in order to explore mitigation measures implemented within the UMCP, capacity building processes on various programme levels were analysed. By applying the Multi-layered Social Resilience framework in the context of the UMCP using a qualitative approach, it was found that exchange between and within administrative levels supported resilience-building processes in terms of mosquito breeding site elimination. “Reactive” and “proactive” capacities were successfully built among programme staff. However, more potential could be tapped among local leaders and household members, by increasing their competence in eliminating breeding sites of malaria vectors. Improving the communication skills of the programme's field workers might support such processes. Together with local leaders, they could act as multipliers of sensitisation messages.

In conclusion, this study showed that urban agriculture is not only widespread in Dar es Salaam, but also a potential malaria risk with regard to breeding sites for *Anopheles* mosquitoes. Urban farming therefore needs to be considered by integrated vector control programmes. However, it should not be overemphasized; rather farmers should be regarded as potential assets in vector control. For example, they could be involved by planting shade trees near water bodies in agricultural areas. More generally, mitigation strategies related to environmental malaria control could build on increased participation of household members within the UMCP intervention area. This may be achieved by building capacities for breeding site elimination, for example through enhanced sensitisation of household members provided by UMCP field workers. These insights, gained by conducting transdisciplinary operational research, can provide a basis for optimising malaria control and urban planning in Dar es Salaam and other malaria-affected SSA cities with comparable climatic conditions.

ZUSAMMENFASSUNG

Weltweit haben das Engagement, der politische Wille und die finanzielle Unterstützung zur Bekämpfung von Malaria ein noch nie da gewesenes Ausmass erreicht. Wenngleich das Ziel der globalen Ausrottung von Malaria in weiter Ferne zu liegen scheint, gibt es doch vielversprechende Ansätze, das Malariaproblem zumindest regional unter Kontrolle zu halten. Aus einigen Regionen konnte die Krankheit, die jährlich etwa eine Million Todesopfer fordert, sogar ganz verdrängt werden. Die am stärksten von Malaria betroffene Region der Erde ist Afrika südlich der Sahara, wo sich zugleich auch die am schnellsten wachsenden Städte der Welt befinden. Die rasante Verstädterung bringt gewaltige Herausforderungen mit sich. Dazu gehören steigende Armut und zunehmende Mangelernährung, die Ausdehnung informeller Siedlungsgebiete, unzureichende Abwassersysteme und hygienische Bedingungen, fehlender Zugang zu sauberem Wasser, sowie Gesundheitsrisiken. Malariaübertragung in städtischen Räumen stellt nach wie vor ein erhebliches Problem dar, wenn auch in geringerem Ausmass als in ländlichen Gebieten.

In Tanzania und in Entwicklungsländern im Allgemeinen ist städtische Landwirtschaft unter anderem eine Reaktion auf den steigenden Bedarf an Nahrungsmitteln in Städten, und wird hauptsächlich in Hausgärten und auf grösseren Freiflächen praktiziert. Einerseits dient sie als wichtige Lebensgrundlage, und trägt wesentlich zur Ernährungssicherung bei. Andererseits kann sie geeignete Brutstätten für Mücken schaffen, und dadurch möglicherweise die Gefahr übertragbarer Krankheiten wie Malaria erhöhen. Es ist jedoch unklar, ob es tatsächlich landwirtschaftliche Faktoren wie das Anbausystem sind, die zur Schaffung von Brutstätten für malariaübertragende Mücken führen, oder ob die zugrunde liegenden geographischen Gegebenheiten wie Topographie und Hydrologie die eigentliche Ursache hierfür darstellen.

Ziel dieser Studie war es, im Kontext umweltbezogener Malariabekämpfung im urbanen sub-saharischen Afrika zu einem besseren Verständnis der Bedeutung von Landwirtschaft in Städten beizutragen. Gleichzeitig sollten mögliche Wege aufgezeigt werden, wie die potentiell davon ausgehende Malariagefahr verringert werden kann. Sämtliche Feldforschungen für diese Studie wurden in den Jahren 2005 und 2006 in der Stadt Dar es Salaam, Tansania, durchgeführt, und waren vollständig in das dort laufende *‚Urban Malaria Control Programme'* (UMCP) integriert. Dieses Programm wird vom *City Medical of Health* in Dar es Salaam geleitet. Hauptziel des UMCP ist die Bekämpfung von Mückenlarven mit

biologischen Larviziden durch ehrenamtliche Mitarbeiter im Feld (*Community-Owned Resource Persons*; CORPs). Der transdisziplinäre Forschungsansatz dieser Studie verknüpfte natur- und sozialwissenschaftliche Herangehensweisen, und bezog Kenntnisse und Kompetenzen von Akteuren im Kontext des UMCP mit ein. Quantitative Methoden umfassten die partizipative Kartierung administrativer Grenzen, eine Querschnittsstudie zur Kartierung landwirtschaftlicher Gebiete, sowie die Erfassung der verschiedenen Anbauarten. Qualitative Methoden bestanden aus semi-strukturierten Schlüsselinformanten-Interviews und *Focus Group*-Diskussionen basierend auf Interview-Leitfäden.

Der Theorierahmen, nach dem sich sowohl die Planung der Studie als auch die Datenanalyse richtete, beruht auf den Konzepten von *Risk, Resilience* und *Threat*. *Risk* wird hierbei als Funktion von *Threat* und *Resilience* betrachtet. Um ein umfassenderes Verständnis der Faktoren zu erhalten, die zum Malaria *Risk* beitragen (d.h. an Malaria zu erkranken), wurden Aspekte von Malaria *Threat* (d.h. Brutstätten mit Larven der malariaübertragenden *Anopheles*-Mücke) und Malaria-*Resilience* untersucht (d.h. *Social Resilience* im Sinne von gesteigerter Kompetenz von Akteuren im UMCP-Kontext).

In einem ersten Schritt wurden die aktuelle flächenhafte Ausdehnung und spezifische Anbaumerkmale städtischer Landwirtschaft ausgewertet. Dies machte deutlich, dass städtische Landwirtschaft in Dar es Salaam weit verbreitet ist, und im Jahr 2005 mehr als 5% des Untersuchungsgebietes landwirtschaftlich genutzt wurden. Hochgerechnet auf das gesamte Stadtgebiet von Dar es Salaam entspricht dies einer Gesamtfläche von beinahe 20 Quadratkilometern, die bewirtschaftet werden. Eine Analyse der raumzeitlichen Veränderungen landwirtschaftlicher Nutzung ergab, dass städtische Landwirtschaft ein dynamisches, nicht aber ein kurzlebiges oder nur übergangsweise auftretendes Phänomen darstellt. Trotz des schnellen Wachstums und der Verdichtung der Stadt ist die Gesamtausdehnung städtischer Landwirtschaft während der vergangenen beiden Jahrzehnte nicht kleiner geworden. Städtische Landwirtschaft scheint also „resilient“ in dem Sinne zu sein, dass sie dem hohen Bevölkerungs- bzw. Bebauungsdruck standhält, oder ihm andernfalls durch räumliche Verlagerung ausweicht.

In einem zweiten Schritt wurde eine partizipative Kartierungsmethode entwickelt, mit deren Hilfe die im Jahre 2005 gesammelten landwirtschaftlichen Daten mit der Datenbank des UMCP verknüpft werden konnten. Dies war notwendig, um die Zusammenhänge zwischen landwirtschaftlicher Nutzung und dem Auftreten von *Anopheles*-Brutstätten untersuchen zu können. Gleichzeitig lieferte diese Methode einen wesentlichen Beitrag zur Optimierung der Abläufe des UMCP. Das Verfahren nutzte einfache Anwendungsmöglichkeiten von Luftbildern und Geographischen Informationssystemen (GIS), und wurde durch die Kartierung von drei urbanen Stadtvierteln *(wards)* von Dar es Salaam mit einer Gesamtfläche von 16,8 km^2 validiert. Die Methode ermöglichte die Verifizierung und Korrektur von Lageskizzen, die von den CORPs im Feld erstellt werden, um ihr Einsatzgebiet festzulegen und sich besser orientieren zu können. Dies erwies sich als Grundstein für flächendeckende Bekämpfung von *Anopheles*-Larven durch das UMCP. Das Verfahren erwies sich als zweckmässig und kostengünstig, und erforderte nur minimale technische Kenntnisse. Dadurch kann es leicht in Malariabekämpfungsprogramme miteinbezogen werden, und auch in anderen Städten unabhängig von deren Grösse Anwendung finden. Die partizipative Kartierungsmethode ist mittlerweile ein integraler Bestandteil des neuartigen vom UMCP entwickelten Management- und M&E[1]-Systems zur routinemässigen Larvenbekämpfung in Dar es Salaam. Dadurch lieferte das Verfahren auch einen Beitrag zur Reduzierung der Malariaübertragung durch den Hauptüberträger, *Anopheles gambiae s.l.*, um 31% (95% CI=21,6-37,6%, p=0,04).

In einem dritten Schritt wurden die erfassten landwirtschaftlichen Daten der Datenbank des UMCP zugeordnet. Dadurch wurde deutlich, das der Anteil von Brutstätten mit *Anopheles*-Larven in landwirtschaftlich genutzten Gebieten 1,7 mal höher war als in anderen Bereichen der Stadt (95% CI: 1,56-1,92). Signifikante geographische Wirkungsvariablen hinsichtlich des Vorhandenseins von *Anopheles*-Larven in Gärten beinhalteten die Lage in tief gelegenen Regionen, die Nähe zu Fliessgewässern, und relativ wasserundurchlässige Böden. Signifikante landwirtschaftliche Wirkungsvariablen umfassten spezifische Saatbeet-Typen, Gärten von mittlerer Grösse, Bewässerung durch Brunnen, und den Anbau von Zuckerrohr oder Blattgemüse. Signifikante negative Wirkungsvariablen waren kleine Gartengrössen, Bewässerung mit Leitungswasser, ausschliesslich auf Regen basierende Landwirtschaft, und Anbau von Hülsenfrüchten oder Obstbäumen. Das Risiko, *Anopheles*-Larven zu finden, war in Regionen mit städtischer Landwirtschaft zwar höher als anderswo, jedoch befanden sich insgesamt weniger als ein Fünftel aller *Anopheles*-Brutstätten in landwirtschaftlich genutzten Gebieten. Die oben beschriebenen Indikatoren für relativ hohe bzw. niedrige Chancen des

[1] M&E: Monitoring & Evaluation

Larvenvorkommens in Gärten können zur Verbesserung der Effektivität von Larvenbekämpfungsmassnahmen beitragen.

In einem letzten Schritt wurden kapazitätsbildende Prozesse auf verschiedenen Programmebenen analysiert, um einige der im Rahmen des UMCP durchgeführten Brutstättenbekämpfungsmassnahmen zu untersuchen. Die Anwendung des *Social Resilience Frameworks* im Kontext des UMCP mit einem qualitativen Ansatz machte deutlich, dass Austausch zwischen und innerhalb der administrativen Ebenen resilienzbildende Prozesse hinsichtlich Brutstättenbekämpfung unterstützte. „Reaktive“ und „proaktive“ Kapazitäten der UMCP-Mitarbeiter und Mitarbeiterinnen wurden erfolgreich aufgebaut. Jedoch könnte noch mehr Potential von lokalen Führungspersönlichkeiten und Haushaltsmitgliedern erschlossen und genutzt werden, wenn man ihre Kompetenz bei der Bekämpfung von Mücken-Brutstätten stärken würde. Die Verbesserung der Kommunikationsfähigkeiten der CORPs könnte solche Prozesse möglicherweise unterstützen. Zusammen mit lokalen Führungspersönlichkeiten könnten sie als Multiplikatoren von bewusstseinsbildenen Informationen agieren.

Abschliessend ist zu sagen, dass städtische Landwirtschaft in Dar es Salaam einerseits weit verbreitet ist, andererseits aber im Hinblick auf Brutstätten für malariaübertragende Mücken auch ein potentielles Malariarisiko darstellt. Städtische Landwirtschaft muss also von umweltbezogenen Malariabekämpfungsprogrammen berücksichtigt werden. Ihre Rolle sollte allerdings nicht überbewertet werden. Stattdessen sollten die Landwirte als potentielle Aktivposten in der Mückenbekämpfung angesehen werden. Sie könnten beispielsweise partizipativ miteinbezogen werden, indem das Anpflanzen von schattenspendenden Bäumen in der Nähe offener Wasserstellen in Gärten gefördert wird. Des Weiteren könnten Malariabekämpfungsprogramme wie das UMCP auch auf mehr Partizipation von Haushaltsmitgliedern aufbauen. Im UMCP-Kontext könnte dies dadurch erreicht werden, dass die Kapazitäten der Haushaltsmitglieder in Bezug auf die Eliminierung von *Anopheles*-Brutstätten gestärkt werden. Dazu könnten die CORPs im Rahmen ihrer täglichen Arbeit vor Ort verstärkt Bewusstseinsbildung betreiben. Diese durch transdisziplinäre Forschung gewonnenen Erkenntnisse können zur Optimierung von Malariabekämpfung und Stadtplanung nicht nur in Dar es Salaam, sondern auch in anderen von Malaria betroffenen Städten im sub-saharischen Afrika beitragen, in denen ähnlichen klimatische Bedingungen herrschen.

MUHTASARI

Michango ya kimataifa, utambuzi wa kisiasa na misaada ya kifedha imeongezeka katika miaka ya karibuni kupambana na malaria, ugonjwa unaoua takriban watu milioni moja kila mwaka. Ingawaje ni vigumu kutokomeza malaria, mbinu zilizopo zina matumaini makubwa katika kusaidia kupunguza malaria .

Nchi zilizo kusini mwa Jangwa la Sahara, zenye miji inayokua kwa kasi, ndilo linaongoza kwa idadi kubwa ya wagonjwa wa malaria. Ukuaji wa miji unaleta changamoto kubwa kama vile kuongezeka kwa umaskini, utapiamlo, makazi yasiyo rasmi, uchafu wa mazingira, ukosefu wa maji salama na matatizo ya afya. Maambukizi ya malaria yanaongezeka katika miji, ingawaje kwa kiasi kidogo kuliko maeneo ya vijijini.

Nchini Tanzania, kama ilivyo kwa nchi nyingine zinazoendelea, moja ya matokeo ya kupanuka kwa miji ni kuongezeka kwa kilimo cha mijini, mara nyingi kikifanyika uani na maeneo yaliyo wazi. Ingawaje kilimo cha mjini ni moja ya njia za kuongeza chakula na kipato, kinaongeza uwezekano wa kutokea magonjwa mbalimbali hasa yale yanayoambukizwa kwa kupitia wadudu waumao, kama vile malaria, kwa kutengeneza au kuongeza mazingira ya mazalio ya mbu. Hata hivyo, hakuna takwimu rasmi zinazoonesha kama ni matumizi ya ardhi kwa ajili ya kilimo au miinuko na mazingira ya maji yanachangia kuweko kwa mazalio ya mbu wa malaria.

Madhumuni ya utafiti huu ni kuchangia uelewa wa mchango wa kilimo cha mijini na matumizi mengine ya ardhi katika mapambano dhidi ya malaria katika miji ya Afrika Kusini mwa Jangwa la Sahara na kutambua njia za kuboresha. Utafiti huu ulifanyika 2005-2006 katika Jiji la Dar es Salaam, Tanzania, kwa kushirikiana na Mpango wa Kudhibiti Malaria Jijini (UMCP). Mpango huu unasimamiwa na Ofisi ya Mganga Mkuu wa Jiji. Mpango huu una madhumuni ya kutumia viuatilifu hai kuua viluwiluwi vya mbu kwa kuwashirikisha wana-jamii.

Utafiti huu mtambuka ulishirikisha taaluma za asili na kisosholojia na kuzingatia uelewa na uzoefu wa wadau mbalimbali wa UMCP. Takwimu zilikusanywa kwa kutumia mbinu shirikishi za kutengeneza ramani za maeneo ya kiutawala, maeneo ya kilimo na uanishaji wa mbinu za kilimo. Mbinu za takwimu za maelezo zilifanyika kwa kutumia dodoso-usu,

watahiniwa maalum na mahojiano ya makundi. Uchambuzi wa takwimu ulitoa mwongozo kwa kuzingatia dhana ya vihatarishi, afueni and tishio, pale ambapo vihatarishi vilionekana kama vigezo vya tishio na afueni. Ili kuweza kuchambua na kuelewa zaidi vihatarishi vya malaria (maambukizi na ugonjwa), dhana ya tishio juu ya malaria (kuwepo kwa mazalio ya mbu waambukizao malaria, *Anopheles*) na afueni dhidi ya malaria (afueni katika jamii kwa minajili ya kuongezeka uwezo wa jamii katika mazingira ya UMCP) vilichunguzwa.

Kwa kuanzia, mazingira ya kilimo katika jiji la Dar es Salaam yalifanyiwa uchunguzi. Takwimu zinaonesha kuwa kilimo mjini kimeshamiri katika maeneo mengi, ikiwa ni zaidi ya 5% ya eneo lote likitumika kwa kilimo mwaka 2005. Hii ni sawa na kilomita za mraba 20 ya eneo lote la jiji la Dar es Salaam. Uchunguzi wa mabadiliko ya muda na eneo ya kilimo mjini umeonesha kuwa kilimo cha mjini kinabadilika kila wakati, ingawaje si kwa vipindi vifupi vifupi. Takwimu zinaonesha kuwa katika miongo miwili iliyopita, licha ya ongezeko la watu na kukua kwa jiji, kilimo hakijapungua. Pia, kilimo hiki kimeendelea kubaki licha ya kuwa na ongezeko la matumizi mengine ya ardhi na kuhimili misukosuko mingine ya kimaeneo.

Katika hatua ya pili, mbinu ya kutumia ramani shirikishi ilitumika ili kuoanisha takwimu za kilimo za mwaka 2005 na takwimu za mazalio ya mbu kutoka UMCP. Hii ni muhimu ili kukadiria mahusiano kati ya ongezeko la eneo la kilimo na mazalio ya mbu wa *Anopheles*. Utaratibu huu umesaidia pia kuimarisha savailensi ya mazalio ya mbu. Mbinu hii ilishirikisha utumiaji wa picha za anga na njia za ukusanyaji takwimu za kijiorafia, na kuhakikiwa kwa kuchora ramani za kata za Dar es Salaam, eneo la ukubwa wa kilometa za mraba 16.8. Hatua hii iliwezesha kuhakiki na kurekebisha michoro iliyochorwa na UMCP na kukamilisha eneo lote lililolengwa kwa ajili ya udhibiti wa vimelea. Mbinu zilizotumika zimedhihirisha kuwa bora na zinazohitaji ujuzi mdogo. Hivyo zinaweza kutumika katika mipango ya kudhibiti mbu wa malaria Dar es Salaam na sehemu nyingine Afrika. Mpango huu shirikishi umetumika na Mpango wa Udhibiti wa Malaria katika Jiji la Dar es Salaam kama sehemu ya uongozi, ufuatiliaji na kutathmini na imechangia kupunguza maambukizi ya malaria kwa asilimia yatokanayo na *Anopheles* kwa 31% (21.6-37.6%).

Katika hatua ya tatu, takwimu za kilimo zilioanishwa na zile za mazalio ya mbu katika UMCP. Hii ilidhihirisha kuwa mazalio yaliyokuwa na mbu wa jamii ya *Anopheles* yalikuwa ni mengi mara 1.7 (1.56-1.92) katika maeneo ya kilimo kuliko maeneo mengine. Viashiria vya kuwepo kwa mazalio ya *Anopheles* katika bustani ilihusisha maeneo ya uwanda wa chini, karibu na vijito, na maeneo yanayotuama maji. Viashirio vya maeneo ya kilimo ni pamoja na vitalu vya mbegu, bustani za wastani, visima vya umwagiliaji na kilimo cha miwa na mboga za majani. Maeneo yenye viashiria hasi ni pamoja na bustani ndogo, uwagiliaji wa kutumia mabomba, kilimo kitegemeacho mvua, na kilimo cha mazao ya kunde na matunda. Ingawa kumekuwa na ongezeko la tishio la kuongezeka kwa vimelea vya *Anopheles* katika maeneo ya kilimo, mazalio kutokana na kilimo jijini yanachangia kwa asilimia 20% tu ya mazalio yote jijini. Utambuzi wa viashiria vya mazalio makubwa (au madogo) vinaweza kutumika kutambua maeneo ya kunyunyizia viauatilifu.

Katika hatua ya mwisho, ili kutathmini mbinu zinazotumiwa na UMCP katika kuboresha uwezo wa wahusika katika ngazi mbalimbali, mpango mzima ulichunguzwa. Ukosefu wa mawasiliano katika ngazi za utawala na utendaji ulichangia kutokuwepo kwa uelewa hivo kuzorotesha ufanisi. Vilevile, ukosefu wa majadiliano kati na ndani ya ngazi hizi ulileta "pengo la ujuzi na uhamasishaji" yaliyoharibu ufanisi. Kuziba pengo la uelewa kunaweza kuchangia uboreshaji wa mpango mzima kwani kungeongeza ufanisi wa wahusika ndani ya mpango na jamii katika kupambana na viatarishi vyote vya mazalio ya mbu wa malaria. Ushirikishwaji wa jamii na upashanaji habari katika ngazi mbalimbali ndio nguzo ya mpango shirikishi wa kupambana na malaria.

Kuhitimisha, utafiti huu umeonesha kuwa, zaidi ya kuwa kilimo kimeenea maeneo mengi katika jiji la Dar es Salaam, pia kinachagia katika ongezeko kubwa la mazalio ya mbu aina ya *Anopheles*. Ni muhimu mbinu za kilimo mjini zikaongezwa na kusisitizwa kama viashiria katika mpango mzima wa kupambana na malaria mjini. Wakulima wa mjini wawe sehemu ya mpango huo. Kwa mfano, wanaweza kushirikishwa kupanda miti ya kivuli karibu na maeneo yenye maji katika miji. Wananchi wawezeshwe kupitia fursa za mafunzo ili waweze kushiriki kikamilifu katika mkakati mzima wa kupambana na malaria. Uwezo wa wanamchi katika kuondoa mazalio ya mbu unaweza kuboreshwa kwa kuendeleza uhamasishaji unaofanywa na UMCP. Matokeo ya utafiti huu uliofanywa kwa kushirikisha taaluma mbalimbali, unajenga msingi wa kutimiza kwa ukamilifu uthibiti wa malaria na mipango mingine katika jiji la Dar es Salaam pamoja na miji mingine iliyoko kusini mwa Jangwa la Sahara iathiriwayo na malaria na yenye hali ya hewa ifananayo na ile ya Dar es Salaam.

PREFACE

The idea for this study originated almost nine years ago in Freiburg, while I was participating at an e-conference titled "Urban and Periurban Agriculture (UPA) on the Policy Agenda"[2]. The timing of this e-conference was ideal, as it was closely related to the topic of my M.Sc. thesis, which I was about to finalise. One year earlier, I had the great opportunity to work in Dar es Salaam in the frame of this M.Sc. thesis, spending several weeks visiting and mapping urban agricultural areas within a project of the German Technical Co-operation (GTZ). During many conversations in Dar es Salaam, I had learnt a lot about the importance of agriculture, particularly from the farmers' point of view, but also from a development-oriented perspective.

At the e-conference, malaria was mentioned as one of the potential health risks related to UPA. This was a topic that I admittedly hadn't dealt with before, and it left me a little bit surprised: while large scale rice production in rural areas appeared to be a plausible risk factor to me in this respect, I simply couldn't imagine that all those gardens I had seen in Dar es Salaam might be contributing to the malaria problem. Curious, and encouraged by my supervisor Axel Drescher, I posted a question in the online discussion forum of the e-conference: "Is there any scientific evidence that urban agriculture increases malaria in cities?"[3] The prompt reaction came from Jo Lines from the London School of Hygiene and Tropical Medicine, whom I later got to know as one of the most knowledgeable experts in this field. Maybe triggered by my somewhat naive question, he made a strong statement by saying that based on his experience, urban cultivation sites were "by far the most important source of malaria vectors in most African towns". A lively debate took off, and participants partly disagreed about what the actual risk factors were. The topic captivated me immediately.

During the years to come, I stayed in touch with colleagues from the Swiss Tropical Institute (STI) and Princeton University, who were working with the Dar es Salaam Urban Malaria Control Programme (UMCP). After a planning meeting in Dar es Salaam, Marcia Castro wrote me an email, asking if I would be interested in being involved in this programme. Motivating meetings with Marcel Tanner in Basel were then followed by a trip to Dar es Salaam in the summer of 2004, together with my partner Constanze Pfeiffer. This was when I

[2] http://www.fao.org/urbanag/
[3] http://www.fao.org/urbanag/010900-2.htm

first met the UMCP team with Michael Kiama, Khadija Kannady and Gerry Killeen. Almost instantly, I knew that this was the team I wanted to work with, and the planned focus of my PhD thesis was soon agreed upon. In line with the partly controversial debate on the topic, the working title of my project was initially formulated as a question: "Malaria risk resulting from urban agriculture – persisting misconception or urgent need for mitigation?"

I feel very fortunate and grateful for having had the support of these inspiring people, who sparked all the developments that finally led to the realisation of this PhD study. It is my sincere hope that the results of this study will not only help answering the question raised above, but also serve as a small contribution towards the overarching goal: reducing the burden of malaria.

Basel, in March 2009 Stefan Dongus

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I would like to express my sincere gratitude to my academic supervisors and mentors around the globe. First and foremost, I would like to thank Prof. Marcel Tanner. He has been the "architect" and main supervisor of this study, and an incredibly generous supporter of all my ideas and plans, while being an inspiring role model in terms of leadership and enthusiasm for work. Prof. Axel Drescher sparked my interest in Tanzania, when I was still his Geography M.Sc. student in Freiburg, by arranging an internship in Dar es Salaam in 1999. His constant support as a supervisor, colleague, mentor and visionary for almost a decade is most appreciated. *Thanks a lot!* Furthermore, I thank Prof. Brigit Obrist who – with a lot of good humour and even more patience – introduced me to the world of qualitative research on social resilience. This "journey" turned out to be an unforgettable, very enriching and exciting experience. I thank Dr. Gerry Killeen for teaching me most of what I know about mosquitoes and their control, and for tirelessly pushing me to higher levels in my work with great enthusiasm and commitment. Last, my sincere thanks go to Dr. Marcia Castro, one of the initiators of this study, for her excellent scientific support, and for hosting me in South Carolina. *Thanks to all of you for your friendship, trust and support!*

During the field work periods for this study, I had the great opportunity to be part of the team of the UMCP in Dar es Salaam. During several legs from 2004 to 2008, I spent a total of more than one year in Dar, which allowed me to see the UMCP growing and maturing, despite all operational challenges. I thank Khadija Kannady for her support, trust, and for sharing precious insights into managerial and administrative issues, and her predecessor, the late Michael Kiama, for encouraging me to work with the UMCP. I would like to express my gratitude to Dr. Deo Mtasiwa and the UMCP managerial crew with Hemedi Abdulla, James Msami, Martin Kalongolela, Bryson Shoo, George William, Abraham Mwambona, Johnson Ndaro, Mercy Kinenekejo, Fanuel Kipesha, Godlove Nyagawa, Aisha Msonde, George Makanyandigo, Issaack Vesso, Matuba Tumaini, and all data entrants at the city council. I am greatly indebted to all other UMCP staff members, especially the CORPs, supervisors and inspectors in Buguruni, Kurasini and Mikocheni, as well as all farmers and residents of Dar es Salaam who contributed to this study by sharing their views with us, and allowing us to enter their compounds. Thanks also go to Dr. Ulrike Fillinger for her continuous support and helpful insights, Prof. Steve Lindsay for thoughtful comments and hosting me in Durham, and Prof. Burt Singer and Derek Willis for stimulating discussions and hosting me in Princeton.

I would like to thank Dr. Hassan Mshinda and my friends and fellow researchers at the Ifakara Health Institute (IHI), Nicodemus Govella, Prosper Chaki, and Bernadette Huho, for many inspiring discussions. My heartfelt thanks go to my field partner Dickson Nyika, for his all his support since we first worked together in 1999. During countless days of mapping in the field, he taught me a lot about life in Dar es Salaam and Tanzanian culture in general. In addition, it was always a great pleasure to spend a relaxing day together with his family in Mtoni Kijichi. *Thanks a lot my friend!* I am also grateful for the competent support of my colleagues Emmy Metta, Selemani Mbuyita and Victoria Mwakalinga, and the committed field team conducting the qualitative studies: Emmanuel Munishi, Ubaldus Tumaini, Finner Evarest, Lydia Mukasa, Ibrahim Madenge and Kulthum Mchuchuli. Thanks also go to Ben Moon and Peter Welk for their assistance in processing the data, Charles Buberwa for his competent GIS advice, Richard Sliuzas for providing access to helpful GIS data, the Photogrammetry Unit at the Surveys and Mapping Division of the Ministry of Lands for providing us the digital aerial imagery used in this study, and Dr. Camillus Sawio and Dr. Phillip Mwanukuzi at the University of Dar es Salaam for their helpful feedback in the early stages of this work. Furthermore, I would like to thank Mzee Ruvu and Mr. Vincent, whose driving skills and general helpfulness I could always rely on. I am also greatly indepted to Loyce Mkumbo for teaching me basic Kiswahili.

During my stay in Dar, I also enjoyed the company of good friends from Europe: Yvonne Geissbühler, the best networked person in Dar es Salaam and a wonderful flatmate, Manuel Hetzel and Michael Vanek, whom I thank for many entertaining hours and good laughs, and Rob van der Werf and Anneke Wieman, whom I thank for hosting me in their house. Thanks also go to Henriette Kolb and Janna Rajpar for providing comfortable shelters.

While in Europe, I had the privilege to work at the STI in Basel, with competent support of experienced staff and students, in a friendly, inspiring and productive open door atmosphere. Thanks a lot to all my colleagues and friends – I truly hope to continue our collaboration in the future. Special thanks go to Prof. Mitchell Weiss and Prof. Jakob Zinsstag for their support, Prof. Don de Savigny, Prof. Jürg Utzinger, Prof. Jennifer Keiser, Dr. Allan Shapira, Dr. Penelope Vounatsou and Prof. Tom Smith for their helpful and motivating feedback to my work, Prof. Christian Lengeler for all his helpful advice, good humour and the initiation of the STI football team, Dr. Laura Gosoniu for numerous private lessons in statistical modelling with STATA, and Eliane Ghilardi, Christine Walliser, Margrith Slaoui, Marianne Hess, Isabelle Bolliger, Yvette Endriss and the IT team for their tireless administrative and logistical support. Thanks also to all my fellow students who contributed to this study in one way or another: Irène Küpfer, Barbara Matthys, Borna Müller, Lena Fiebig, Michael Bretscher, Peter Steinmann, Stefanie Knopp, Karin Gross, Tippi Mak, Daniel Weibel, Stefanie Granado, Dominic Gosoniu, Susan Rumisha, Bianca Plüss, Ricarda Windisch, Daria Czendlik, Patricia Schwärzler, Julie Balen, Mwifadhi Mrisho, Sandra Alba, Ellen Stamhuis, Josh Yukich, Valerie Crowell, Nakul Chitnis and Melissa Penny. For the days during which I was working in Freiburg, the Institute of Physical Geography (IPG) always kept me a workspace. I am very grateful for the support of my colleagues and friends at the IPG, particularly Prof. Rüdiger Glaser, Prof. Rüdiger Mäckel, Dr. Elke Ecker, Dr. Magigi Wakuru, Dr. Steffen Vogt, Philipp Weckenbrock and Angelika Schuler.

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Even before the onset of this study, Petra Jacobi, Dr. Jörg Amend and Suzan Kiango facilitated my first hands-on experience on urban agriculture in Dar es Salaam. Pay Drechsel and Eveline Klinkenberg in Ghana later helped me to shape my research ideas. *Thanks a lot* for this, and for hosting me in Dar es Salaam, Accra and Kumasi!

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1 INTRODUCTION

This dissertation investigates the importance of urban agricultural land use in the context of environmental malaria control in urban sub-Saharan Africa, and potential mitigation options. In the first chapter, an introduction is given to malaria history, parasites, vectors and clinical features, and global action to reduce the disease burden. This is followed by background information on urbanisation, urban agriculture, urban malaria, and potential correlations between urban agriculture and malaria, with a special focus on Dar es Salaam, the study area. Finally, an overview is given of the city's history and geography, and the ongoing Dar es Salaam Urban Malaria Control Programme.

1.1 Malaria

History

Malaria was recognised as a disease in China almost 5,000 years ago. Its symptoms have been described in many other parts of the world since then (Carter & Mendis 2002), and the curative effects of quinine have been known for hundreds of years. Malaria parasites in human blood were first described in 1880 by Laveran, a French army surgeon in Algeria. However, it was not until 1897 that Ronald Ross discovered in India that malaria is transmitted by mosquitoes (Warrell & Gilles 2002: 1). This discovery sparked a new era of research related to malaria control, which at that time still affected large areas of North America and Europe, including Germany and parts of Switzerland (Bruce-Chwatt & Zulueta 1980, Carter & Mendis 2002). With the disease vector now known, larvicides to prevent the breeding of mosquito larvae in water were developed. At the beginning of the Second World War, the strong insecticidal action of DDT was discovered, and the subsequent spraying of insecticides against adult mosquitoes revolutionised malaria control. Moreover, treatment options for malaria improved substantially after chloroquine was developed in 1934. The final eradication of malaria was envisioned in the 1950s when DDT application showed very promising results in reducing the malaria burden (Warrell & Gilles 2002: 2). Despite great successes in the Caribbean, parts of Asia and South-Central America, and eradication in Europe and North America during the following decades, the efforts did not succeed in tropical Africa and many parts of Asia (Carter & Mendis 2002, Greenwood et al. 2005)

(Figure 1.1). This failure can partly be attributed to emerging drug and insecticide resistance, but also to the fact that in sub-Saharan Africa, ideal climatic conditions for transmission coincide with the ranges of the most efficient vector mosquitoes in the world (Killeen et al. 2004). Today, with unprecedented political will and financial support, malaria eradication is back on the global health agenda (Roberts & Enserink 2007, Tanner & de Savigny 2008).

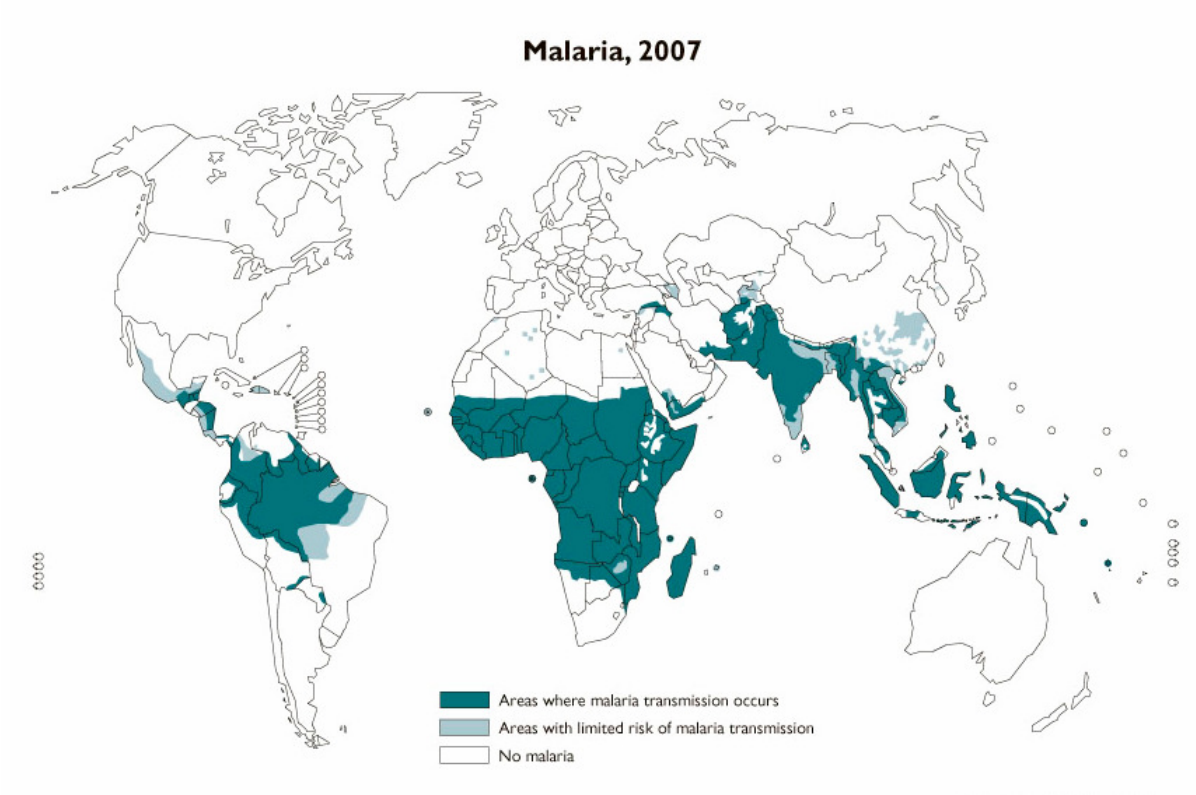

Figure 1.1: Global malaria risk areas, 2007
Source: World Health Organization 2008 (www.who.int/globalatlas)

The malaria parasite

Malaria is caused by four species of protozoan parasites belonging to the genus *Plasmodium*, namely *P. falciparum*, *P. vivax*, *P. malariae* and *P. ovale*, and can be transmitted by the bite of several species of female anopheline mosquitoes. *P. falciparum* causes the majority of infections in Africa, and the most severe disease and mortality (Greenwood et al. 2005). Apart from *P. malariae* which can also be found in other mammals (Warrell & Gilles 2002), these parasites require two hosts to complete their life cycle; an anopheline mosquito and a human being. During a blood meal, a malaria-infected female *Anopheles* mosquito inoculates sporozoites into the human host. In the human liver, these develop into merozoites that then infect red blood cells. During this blood stage, when the parasites further mature and replicate, they are responsible for the clinical manifestations of the disease. Some parasites then differentiate into gametocytes that are ingested by an *Anopheles* mosquito during a blood meal. In the mosquito, the parasite matures and replicates further, developing into sporozoites. Inoculation of the sporozoites into a new human host perpetuates the malaria life cycle (Figure 1.2) (CDC 2009, Warrell & Gilles 2002).

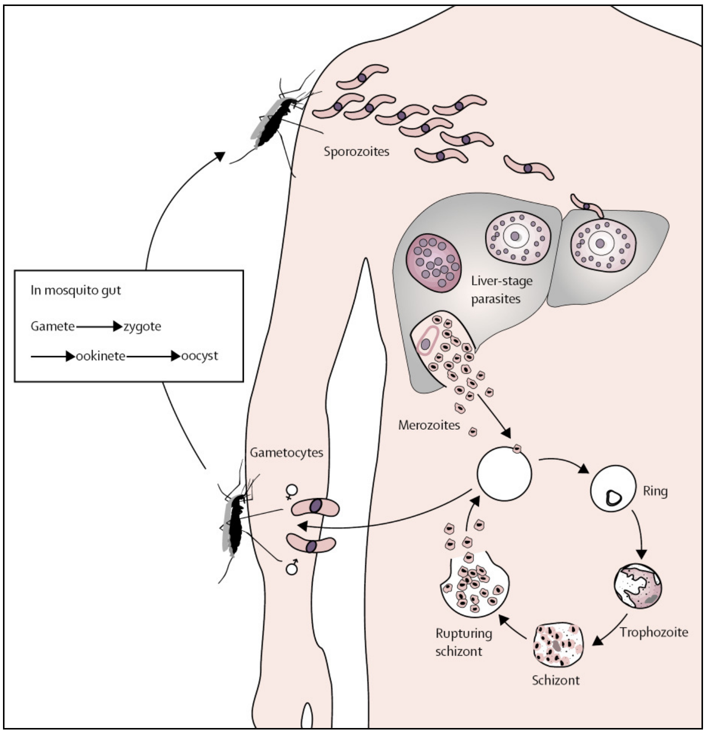

Figure 1.2: Life cycle of the malaria parasite
Source: Greenwood et al. (2005)

Malaria vectors

Only mosquitoes of the genus *Anopheles* are able to transmit human malaria. They are most common in tropical and subtropical regions, and are only found at altitudes below 2500m (Warrell & Gilles 2002: 59). The major vector species occurring in sub-Saharan Africa are *Anopheles gambiae* Giles, *An. arabiensis* Patton, *An. funestus* Giles, *An. merus* Dönitz (East Africa) and *An. melas* Theobald (West Africa) (Gillies & De Meillon 1968). *An. gambiae* belong to the most efficient vectors of malaria known from anywhere in the world (Gillies & De Meillon 1968), and are the most important vector in Dar es Salaam (Geissbühler et al. 2007a). *Anopheles* larvae generally breed in temporary small ponds, pools and puddles, and in more permanent habitats such as marshes. Most aquatic habitats are freshwater, although some *Anopheles* species also breed in saline waters. Most anophelines avoid polluted waters for breeding (Warrell & Gilles 2002: 70). The preferred breeding sites of *An. gambiae* are shallow open sun-lit pools, ranging from borrow pits, drains, brick pits, car tracks, hoof prints around ponds and water holes, to pools resulting from the overflow of rivers or left by receding rivers, backwaters, and rainwater collecting in natural depressions (Gillies & De Meillon 1968: 209).

Figure 1.3: *Anopheles* breeding site

1 – puddle in overview; 2 – puddle in close up, high density of *Anopheles* larvae (longish and thin) and pupae (roundish dark spots), freshly emerged adults at the edges. Source: Fillinger et al. (2004)

Disease burden and global action

Malaria is the most important parasitic infection in people (Greenwood et al. 2005). Even though it is difficult to make accurate estimations of the disease burden (de Savigny & Binka 2004), most sources state that about one million people die every year because of malaria, mainly children under 5 years of age living in Africa (Greenwood et al. 2005, Hay et al. 2005, WHO 2008). According to the World Malaria Report 2008 of the World Health Organization (WHO 2008), an estimated 200-300 million cases occur annually, with 3.3 billion people at risk of malaria in 2006. More than 70% of these lived in areas at risk of *P. falciparum* transmission in 2007 (Guerra et al. 2008). Apart from the social burden, the macroeconomic consequences of malaria are severe. Malaria is seen as both a disease of poverty and a cause of poverty (Carter & Mendis 2002, Sachs & Malaney 2002).

Today, more than 40 years after the inauguration of the Global Malaria Eradication Program in 1955, key organisations are again debating if eradication, i.e. the global reduction of malaria prevalence to zero, should be an explicit goal of malaria control efforts (Tanner & de Savigny 2008). However, many experts consider the goal of *eradication* to be unrealisable in the foreseeable future. At the current stage, the move from *control* to *elimination* (i.e. regional reduction of malaria prevalence to zero) is seen as a quantum leap (Hommel 2008). Nevertheless, global commitment and action has reached an unprecedented level. Three out of the eight Millennium Development Goals (MDGs) of the United Nations are directly linked to reducing the burden of malaria, namely MDG 4 (reduce child mortality), MDG 5 (improve maternal health), and MDG 6 (combat HIV/AIDS, malaria, and other diseases) (UN 2008a). Besides, financial resources through the Global Fund to fight AIDS, Tuberculosis and Malaria, the World Bank's Booster Programme, the US President's Malaria Initiative and other donors such as the Bill and Melinda Gates Foundation are increasing (Tanner & de Savigny 2008). Furthermore, the Roll Back Malaria Partnership (RBM), launched by the WHO in 1998, unveiled the Global Malaria Action Plan in September 2008 (RBM 2008). This action plan charts a possible way forward to scale up malaria control in the short term, then eliminate and, eventually, eradicate malaria in the future (Coll-Seck 2008).

The malaria control strategies promoted by the WHO comprise the following four key interventions, where indicated: (1) prompt access to effective treatment (preferably based on laboratory-confirmed diagnosis and Artemisinin-based combination therapies (ACTs); (2) mosquito control with insecticide-treated nets (ITNs), preferably long-lasting insecticidal nets (LLINs); (3) mosquito control by indoor residual spraying of insecticides (IRS), including DDT; and (4) prevention of malaria in pregnancy (WHO 2008).

Some of these malaria control tools have been known since decades, and no "magic bullet" seems to be in sight. Nevertheless, the search for new tools is in full swing. A lot of hopes are currently put on the development of a malaria vaccine, such as the RTS,S/AS vaccine for children that might be available in a few years from now (Abdulla et al. 2008).

Clinical features

Malaria can have various presentations depending on factors such as the parasite species, but also the location, age, and the immune, health and nutrition status of the patient. Malaria is an acute febrile illness that classically manifests itself in periodic febrile paroxysms. Patients often have symptoms such as fatigue, headache, dizziness, body pain, chills, nausea and vomiting (Warrell & Gilles 2002). Severe malaria is predominantly due to *P. falciparum.* In African children, its most frequent presentations are severe anaemia and cerebral malaria (Greenwood et al. 2005). This presentation of the disease often leads to coma, and if untreated, to the death of the patient. Children under five years of age and pregnant women are most vulnerable to suffering from severe forms of the disease (Warrell & Gilles 2002).

1.2 Urbanisation

The world population is growing fast. During the last 50 years, the growth of the urban population, in particular, caused by rural-urban migration and natural population growth has been dramatic. In the year 2008, for the first time more people were living in cities than in rural areas. The speed and the scale of this growth, especially in less developed regions (Figure 1.4), pose enormous challenges to individual countries as well as to the world community (Howorth et al. 2001, UN 2007b, 2008b). The challenges include unemployment, growing poverty, food insecurity, malnutrition, deterioration of the environment, as well as inadequate infrastructure regarding health services, water supply, sanitation and waste management (Hardoy et al. 2001, Harpham & Tanner 1995, UNFPA 2007).

In Africa, almost 4 out of 10 people will live in cities by 2010. Therefore, Africa still is the least urbanised continent, and there are distinct regional differences. Whereas 59% of people in Southern Africa live in urban areas, this is only the case for 24% of people in Eastern Africa. By 2050, however, the situation will probably change drastically, particularly in Southern Africa, resulting in an urbanisation rate similar to the one in Western Europe (UN 2008b).

One of the consequences of urbanisation in Africa is the development and growth of informal settlements that can be observed in all African countries except South Africa, Libya and Egypt (UN-Habitat 2006). A characteristic of urbanisation in Africa is the absence of concomitant economic growth, which usually accompanies urbanisation in other parts of the world. Possible explanations for this are the strong growth of the informal sector whose economic relevance is rarely represented in official statistics, and the migration pressure from crisis areas and poor rural regions (UNU 1997).

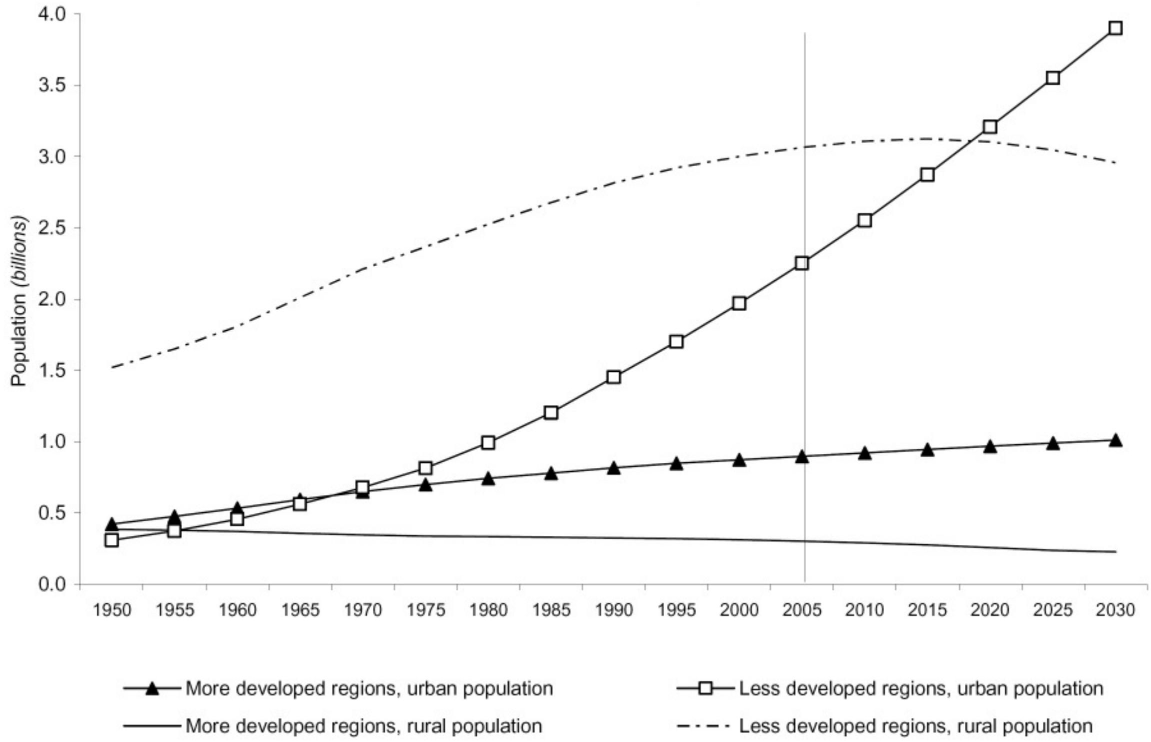

Figure 1.4: Urban and rural population of more developed regions and less developed regions, 1950 – 2030

Source: UN (2008b)

Another result of rapid urbanisation is a dramatic growth of urban poverty, already affecting 50% of the urban population in sub-Saharan Africa. This phenomenon is associated with other negative effects. Almost 30% of urban residents in SSA do not have access to safe drinking water, 20% do not avail of sanitary facilities, and residents of informal settlements suffer more from malnutrition than other city dwellers (UN-Habitat 2006).

The process of urbanisation also entails a range of health risks. During the nineties, urban health increasingly gained attention in the international debate (Harpham & Tanner 1995: 1). Infectious diseases such as diarrhoeal diseases and intestinal worms in relation to water, soil and food are common, although preventable (Hardoy et al. 2001: 37f). The high prevalences of HIV/AIDS measured in Africa are generally even higher in urban regions compared to rural areas (Buve et al. 2002). Although to a lesser extent than in rural areas (Robert et al. 2003), malaria transmission in urban settings is a significant problem, too (Granja et al. 1998, Imbert et al. 1997, Trape et al. 1993). Chronic diseases such as diabetes are on the rise (Lorenz & Mtasiwa 2004).

However, living in urban areas also has many advantages. Apart from jobs, these comprise better access to education and health facilities, a broad range of services, trade, markets, culture, entertainment, public transport, electricity, connection to the transport network and sanitation infrastructure (UNFPA 2007).

1.3 Urban agriculture

Farming in cities is a world-wide phenomenon. The United Nations Development Programme estimates that 800 million people are engaged in urban agriculture (UA) (Smit et al. 1996). UA is an industry located within or on the fringe of a town, city or metropolis, which grows or raises, processes and distributes a diverse range of food and non-food products, using largely human and material resources, products and services found in and around that urban area, and in turn supplying human and material resources, products and services largely to that urban area (Mougeot 2000b). UA includes horticulture, floriculture, forestry, aquaculture, and livestock production as well as related activities like the delivery of inputs and the processing and marketing of products (Mougeot 2000a) and is typically recognised as an informal activity and a response to crisis (Jacobi et al. 2000b).

According to the "Atlas of Food" (Millstone & Lang 2008), many households are involved in urban food production in SSA. The proportion of households practicing subsistence agriculture is 50% in Accra, Ghana, 45% in Lusaka, Zambia, and even 80% in Libreville, Gabon. In Harare, Zimbabwe, 80% of households practice UA in summer and 60% in winter, while 37% of the families in Dar es Salaam, Tanzania, are involved in UA. 60% of the vegetable demand in Dakar, Senegal, and as much as 80% in Accra are covered by urban production. In Dar es Salaam, almost 30% of the total demand for food is met by urban agriculture. These numbers illustrate the importance of UA for food security in cities of SSA (Millstone & Lang 2008).

Urban food production is closely linked to environmental factors. The preservation of green open spaces and the diversification of urban habitats for humans, animals and vegetation as well as of resource niches all contribute to sustainable city development. At the same time, these factors allow for higher biodiversity, reduced noise and air pollution, and recycling of organic solid waste as well as waste water. UA thus can be part of the vision of sustainable future city development (Drescher 2003, Howorth et al. 2001, Magigi 2008). Both UA on an individual basis and organised in groups of farmers can fulfil the basic needs of the urban population in an environmentally-friendly and sustainable manner (Drescher 1998, FAO-COAG 1999, IFPRI 1998).

Agriculture contributes to development (World Bank 2008), and the provision of healthy nutritious food can contribute positively to the health of consumers (Mougeot 2000a). UA is an important supply source in developing-country urban food systems and a critical food-security valve for poor urban households. It affords a cheap, simple, and flexible tool for productively using open urban spaces, treating and recovering urban solid and liquid wastes, generating employment and income; and serves as livelihoods, adding value to products, managing freshwater resources more sparingly, and resolving otherwise incompatible urban land use issues (Mougeot 2000a, Nugent 1997). With the decline of the economy in many African countries in the seventies, agriculture became the most important source of income and food security in urban areas. In Europe, for example in Germany and the United Kingdom, a comparable situation was the establishment of allotment gardens[4] as a reaction to the challenging economic conditions two hundred years ago (Briggs & Mwamfupe 2000, Holmer et al. 2003, Schilter 1994, TUAN 1994).

On the international agenda, UA is seen as a mitigation option to the challenges related to the fast growth of cities in developing countries. In the famous "Brundtland Report" from 1987, the World Commission on Environment and Development called for promotion of UA. "Urban agriculture that is accepted by the public and publicly supported might be important for city development and improve the food supply of the urban poor" (Hauff 1987: 252). Urban agriculture is also increasingly discussed as a livelihood strategy in view of climate

[4] Allotment gardens are characterised by a concentration of several land parcels of about 200-400 m^2 that are assigned to individuals or families, usually organised in an association. The parcels are cultivated individually. An allotment garden is made legally available by the city authorities to the association to be used exclusively for growing of vegetables, fruits and cut flowers, but not for residential purposes (Holmer et al. 2003).

change and energy saving. The World Meteorological Organization recommends that countries should invest more in urban agriculture (UN 2007a).

A range of international agencies are actively supporting urban agriculture and urban farmers. Examples are development agencies such as the German Technical Cooperation (GTZ), the United Nations Development Programme (UNDP), the United Nations Food and Agriculture Organisation (FAO) (Mougeot 2000b), and the Resource Centres on Urban Agriculture and Food Security (RUAF), an international network of regional resource centres providing training, technical support and policy advice to governments, producer organisations, NGOs and other local stakeholders. Furthermore, several research partnerships focus on urban agriculture and its development, such as the Consultative Group on International Agriculture Research (CGIAR) in its "Urban Harvest" initiative, and the International Development Research Centre (IDRC).

Despite this support, agriculture in urban areas can also engender health risks, which often leads to a rather sceptical attitude towards UA in the public health sector (Mougeot 2000b). If not properly managed (Buechler et al. 2002), this is especially true for the use of wastewater for irrigation. Other factors that can lead to contamination of the food products with heavy metals and pathogens and thus constitute potential threats to the health farmers and consumers are contaminated soil, polluted air, and incorrect application of agrochemicals (Birley & Lock 1999, Cissé & Tanner 2001, Drescher 1994, Mougeot 2000b). Livestock keeping in urban areas may cause damages to the urban environment (Mlozi 1997). Furthermore, urban farming may provide aquatic habitats for mosquito larvae, such as wells used for irrigation (Robert et al. 2003, Trape & Zoulani 1987). However, there is no evidence that irrigation in the city increases urban malaria, although green open spaces can provide mosquito resting places and breeding sites if clean water is used (Klinkenberg et al. 2008, Klinkenberg et al. 2005).

1.4 Study area: Dar es Salaam

History

Dar es Salaam was founded in the 1860s by Sayid Majid bin Said, the Sultan of Zanzibar, who also established the port of Dar es Salaam in 1867. In 1884, Germany became the first colonial power in Tanzania. Seven years later, Dar es Salaam was chosen to be the capital of German East Africa *(Deutsch-Ostafrika)* (Obrist 2006: 72). Traces of the German colonial period are still visible in the city today, for example the pattern of the road network in the city centre, and buildings such as the Ocean Road Hospital (Becher 1997, Vorlaufer 1970). From 1905 to 1907, up to 300.000 people died during the biggest rebellion against the colonial oppression, the so-called "Maji-Maji-Rebellion". During the First World War, German East Africa was taken over by the British, and named *Tanganyika* under their mandate until independence in 1961. In 1964, the islands of Zanzibar joined mainland Tanganyika, finally forming the present "United Republic of Tanzania". Dar es Salaam remained Tanzania's capital until 1973, when Dodoma became the new capital under the first president of independent Tanzania, Julius Nyerere. This shift to Dodoma, situated in the geographical centre of Tanzania (Figure 1.6), was part of the decentralisation policy of African socialism *(ujamaa)* under Nyerere (Engelhard 1994: 29f). Today, Dar es Salaam is a bustling port city (Figure 1.5), with a commercial centre, high-rise buildings, supermarkets, traffic congestion, and mushrooming squatter settlements (Obrist 2006: 71).

Figure 1.5: Dar es Salaam city centre and port entrance

Picture: Dongus 2006

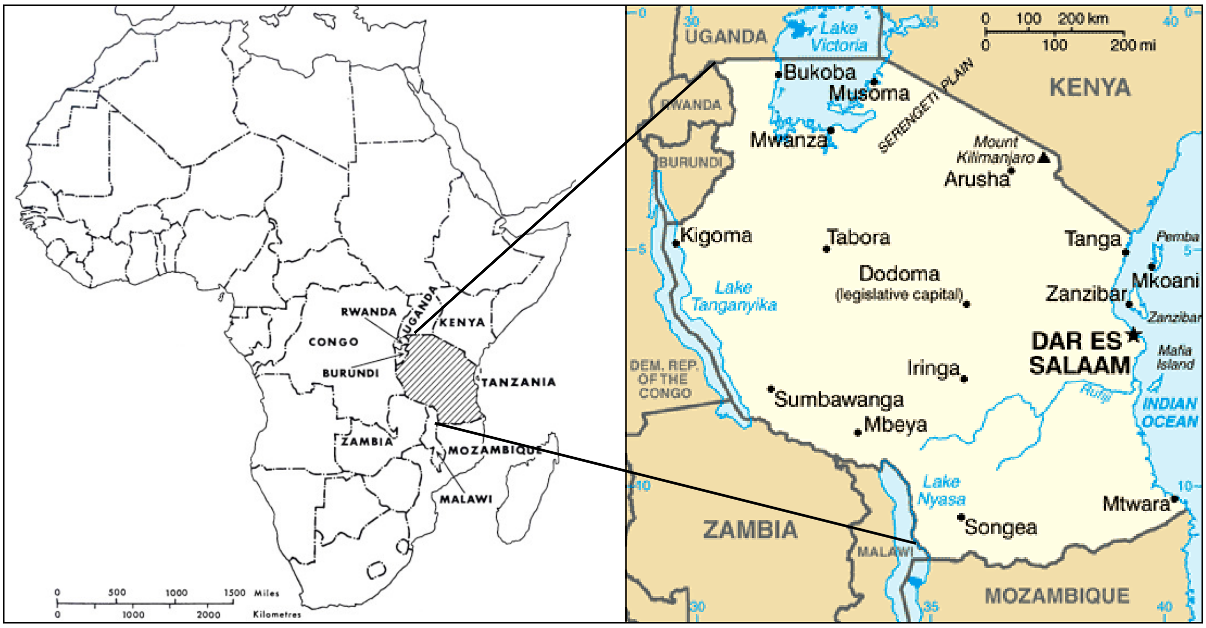

Figure 1.6: Map of Tanzania and its location in Africa

Source: Africa: Berry (1971), Tanzania: http://wikipedia.org/wiki/Tanzania

Geography

About a quarter of Tanzania's 38 million inhabitants were living in urban areas in 2005 (UN 2007b, 2008b), with Dar es Salaam by far the country's largest city. Located 750 km south of the Equator and bordered by the Indian Ocean to the east, large parts of the city are located on a coastal plain rising only a few meters above sea level. Further west and especially along the arterial roads leading out of town (Figure 1.7), the fringe of the city expands to the higher inland plateau, where the altitude reaches one hundred meters and higher (ITC Enschede & University of Dortmund 2008). The administrative city region covers an area of almost 1,400 km^2 (Castro et al. 2004). The coastal plain is located in an area of fairly uniform relief with slopes invariably less than 3%, except along the immediate margins of the two big river valley systems, the Msimbazi river in the central and the Mzinga (Makani et al.) river in the southern part of Dar es Salaam (Temple 1970: 36). Dar es Salaam has a hot and humid tropical climate with two rainy seasons, an intense one observed during the months of March and April, and a milder one occurring in November and December. The average yearly amount of rainfall is about 1100 mm per year. The mean daily temperature is about 26°C, with seasonal ranges of about 4°C, and daily ranges of about 8°C. The relative humidity reaches 100% on almost every night of the year and rarely drops below 55% during the day (Bargman 1970). The Dar es Salaam region constitutes an area with endemic and perennial malaria, with transmission occurring during the entire year (MARA/ARMA 2002).

According to the FAO-UNESCO classification[5], the dominant soils in the coastal plains of the Dar es Salaam Region are *Ferralic Arenosols*. These soils are poor in nutrients, often clayey and partly sandy, and therefore relatively unproductive for agricultural use (Engelhard 1994: 132, Manshard & Mäckel 1995: 51f, Schultz 1989: 615). In the floodplains of the river valleys, alluvial soils such as *Eutric Fluvisols* and *Eutric Gleysols* are dominant (Muster 1997: 21). The geological subsoil is dominated by marine and coral limestone. Although these soils are not particularly fertile (Sawio 1998), soil samples taken from open spaces used for agriculture showed moderate to high fertility, mainly resulting from use of organic fertilisers such as chicken manure (Amend & Mwaisango 1998: 18).

Urbanisation in Dar es Salaam

Dar es Salaam is the *de facto* capital and main administrative, commercial, industrial and transportation centre (Howorth et al. 2001) with more than 2.9 million inhabitants in 2007 and an average annual population growth rate estimated at 4.3% over 2005-2010 (UN 2008b). The growth of the city is characterised by planned and unplanned spatial expansion, as well as densification (Figure 1.7 and Figure 1.8). Based on Sliuzas (2004), Amer (2007) (Figure 1.7) and updated information provided by the ITC Enschede and the University of Dortmund (2008), the urban area of Dar es Salaam covered a total of 344 km^2 in 2002.

Figure 1.8 exemplifies this expansion and densification in Keko ward, which is located about 2 km southwest of Dar es Salaam's city centre. In this area, informal settlements filled up the open spaces between industrial areas that had emerged first. The residential houses in the informal settlements were even built directly bordering the river that runs diagonally from the northwestern to the southeastern corner of the image. The relatively low lying and sometimes flooded part of the river valley in the southeastern part of the image (outlined in black) was entirely used for agricultural production in 1992 (Dongus 2001). In the year 2007, large parts of this area were built up with industrial structures and informal settlements, but two small areas outlined in black were still used for agriculture.

[5] http://www.fao.org/Wairdocs/ILRI/x5546E/x5546e04.htm

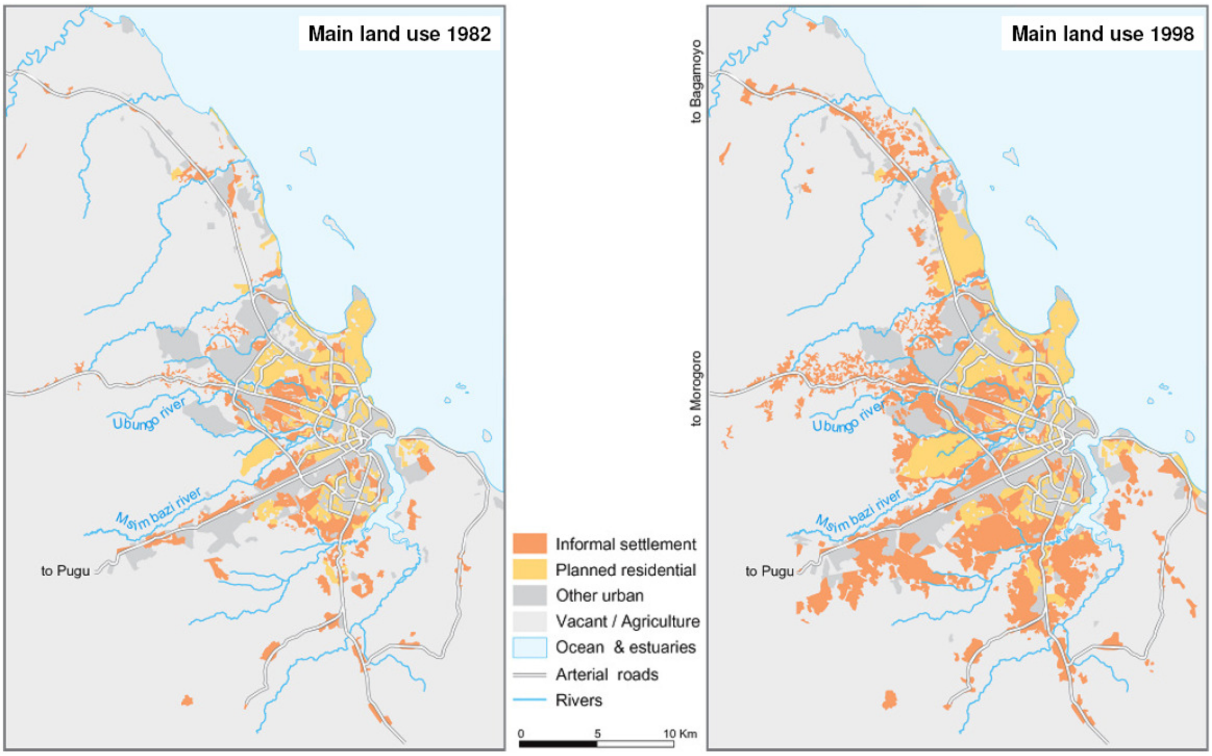

Figure 1.7: Urban Expansion and major land uses in Dar es Salaam in 1982 and 1998
Source: Amer (2007: 102)

1.5 Urban agriculture in Dar es Salaam

Urban agriculture in Tanzania appears to have "grown up in response to need and to the opportunity afforded by the low-density urban pattern" (Kyessi 1997: 28), and is regarded as a livelihood strategy (Magigi 2008, Redwood 2008). It is estimated that Dar es Salaam's low-income residents spend 85% of their earnings on food (Redwood 2008). 8-13% of the urban population are not able to afford sufficient food to meet nutritional standards (PMO 2004). People of all socioeconomic levels are practicing UA throughout Tanzanian towns and cities (Mlozi 1997, Sawio 1993). By 1988, one in five people of working age in Dar es Salaam were involved in some form of UA (Smit et al. 1996). Since the 1970s, Dar es Salaam has been experiencing an unprecedented growth of the informal sector, which absorbs more than half of the urban population (United Republic of Tanzania 1996). This phenomenon goes along with economic recession, rural-to-urban migration and a decrease in both formal employment opportunities and real income among those employed in the formal sector (Vorlaufer 1989: 611). UA is one of the major activities practiced in the informal sector (Kiama 2003, Mascarenhas 1994, United Republic of Tanzania 1996). A large number of farmers on open spaces obtained their plots during the economic crisis in the first half of the 1970s. In this period, the Tanzanian government encouraged people in the city to cultivate every available piece of land (Stevenson et al. 1994). The decline of the economy worsened in the 1980s, resulting in shortages of even basic foodstuffs. The response of urban dwellers to this pressure was to try to produce as much of their own food as possible (Briggs 1991). Much of the agricultural expansion until the mid 1980s took place in the periurban zone (Briggs & Mwamfupe 2000). Even until recent years, poverty continues to be a primary concern for the majority of Dar es Salaam's residents (TzPPA 2002/03).

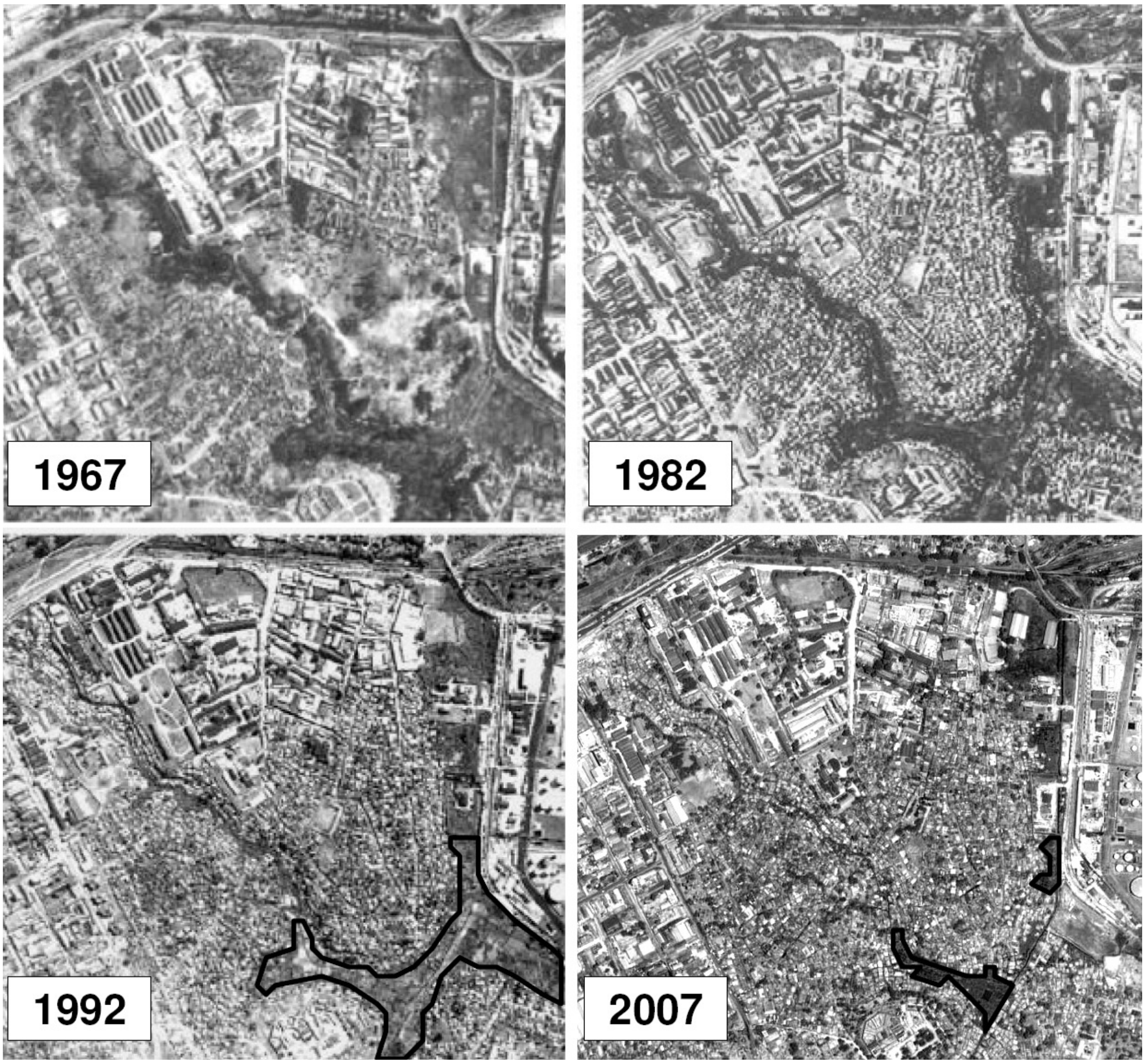

Figure 1.8: Expansion and densification in Dar es Salaam, Keko Mwanga

Informal settlements and planned industrial areas. Marked in black (1992 and 2007): Open spaces used for urban agriculture. Source of aerial photographs 1967, 1982, 1992: Sliuzas (2004) & Dar es Salaam Department of Surveys and Mapping; 2007: Google Earth™. Mapping: Dongus.

Provided that valid arrangements regarding land tenure exist, UA is recognised in urban planning and land management legislation in Tanzania. The “Urban Farming Regulations of 1992” set out under the Town and Country Planning Ordinance (CAP 378) state that urban farming means “the carrying out of plant and animal husbandry activities within statutory township boundaries” (Jacobi et al. 2000a, Magigi 2008). There are no restrictions regarding crop production, and urban livestock production is permitted (Jacobi et al. 2000a, Mlozi 1997). Based on the Environmental Planning and Management (EPM) approach, the Strategic Urban Development Plan for Dar es Salaam designated special land zones for agriculture, including corresponding development conditions (SDP 1998, 1999). This approach has been widely accepted by the Ministry responsible for Land Development (Kitilla & Mlambo 2001). However, despite the existence of these generally favourable and partly detailed regulations, these seem to be poorly enforced by authorities, urban planners and managers in land use planning practice (Magigi 2008).

The most prominent urban agricultural activities in Dar es Salaam comprise home gardening, livestock production and market-oriented production on public and private open spaces (Jacobi et al. 2000a) (Figure 1.9). This includes rearing of livestock such as chicken and cattle, cultivation of fruit trees, but most importantly vegetable production (Kiango & Likoko 1996). UA takes place on private as well as public land, residential plots and industrial or institutional areas. In many cases, public land is used without any official agreement and is illegally encroached, often without secure land rights (Jacobi et al. 2000a). In Dar es Salaam, urban production is the most important source of supply for leafy vegetables (Stevenson et al. 1994: 1), with more than 90% of leafy vegetables produced on open spaces and in home gardens (Stevenson et al. 1996).

Home gardening

Home garden production or backyard farming (Figure 1.9) is by far the most important urban production system in Dar es Salaam in terms of the number of households involved. It is practised throughout the whole city area, and among all income groups. Urban home gardens belong to a residential plot and are cultivated by one or more persons of the same household, with minimal input. In contrast to open space production, home gardening is commonly done by women. The cultivation of the land is legal, as the right to use it is linked to the tenure of the house or the permission of the landlord (Jacobi et al. 2000a: 263). Home gardening is mainly subsistence oriented, i.e. the majority of vegetables grown in home gardens are consumed by the gardeners themselves, their relatives and neighbours. Only few of these vegetables are sold (Stevenson et al. 1994).

Figure 1.9: Open space production and home gardening

Left: Open space production in Mikocheni near Millennium Towers. Right: Home gardening in Kurasini near Mandela Bridge. Pictures: Dongus 2005

Livestock production

Urban livestock production in Dar es Salaam includes keeping of cattle, poultry (broilers as well as layers), local fowl and goats. About 16% of the urban milk consumption originates from urban production, which indicates the importance of cattle (Jacobi 1998, Jacobi et al. 2000a: 265). While cattle are found exclusively among medium- or high-income groups, the keeping of goats and chicken can also be found in low-income groups (Jacobi 1998: 6).

Open space farming

An total area of 6.5 km^2 equal to 4% of the urban area was used for vegetable production on open spaces in 1999 (Dongus 2001) (Figure 1.9 and Figure 1.10). Vegetable production on open spaces in Dar es Salaam is mostly market-oriented and therefore an important, and very often the only source of income for the farmers involved (Kiango & Likoko 1996). The importance of open spaces used for agriculture is made clear by the fact that more than 90% of all leafy vegetables appearing on the city's markets originate in the open spaces and home gardens (Stevenson et al. 1996). It is estimated that at least half of the products come from open spaces (Jacobi 1997: 3). Farming on open spaces is generally done by men on an individual basis. Few of the farmers in open spaces belong to a formal or informal organisational structure (Kiango & Likoko 1996). Very often, there is a clear separation between producers' places of residence and their production plots, with distances ranging up to several kilometres (Stevenson et al. 1994: 19). One of the crops most frequently cultivated on open spaces is *mchicha* (Amaranthus spp.), a particularly profitable leafy vegetable crop that is a popular component of the traditional meal together with maize porridge (*ugali*) (Jacobi et al. 1999).

1.6 Urban malaria in Africa and in Dar es Salaam

14 to 18 million new malaria cases are reported yearly in Tanzania. As the leading cause of outpatient visits, deaths of hospitalised people and admissions of children less than five years of age at medical facilities, malaria represents one of the most important obstacles to economic development and foreign investment in Tanzania (MOH 2002). Over a million cases are reported by the health facilities every year (Mtasiwa et al. 2003), though malaria is grossly overreported (Makani et al. 2003).

In areas prone to malaria, such as sub-Saharan Africa, which has some of the highest rates of *P. falciparum* transmission (Robert et al. 2003), urbanisation has major implications for the transmission and epidemiology of malaria (Lines et al. 1994, Warren et al. 1999). Rapid urbanisation affects anopheline species in the environment in terms of diversity, numbers, survival rates, infection rates and the frequency with which they bite people (Hay et al. 2005).

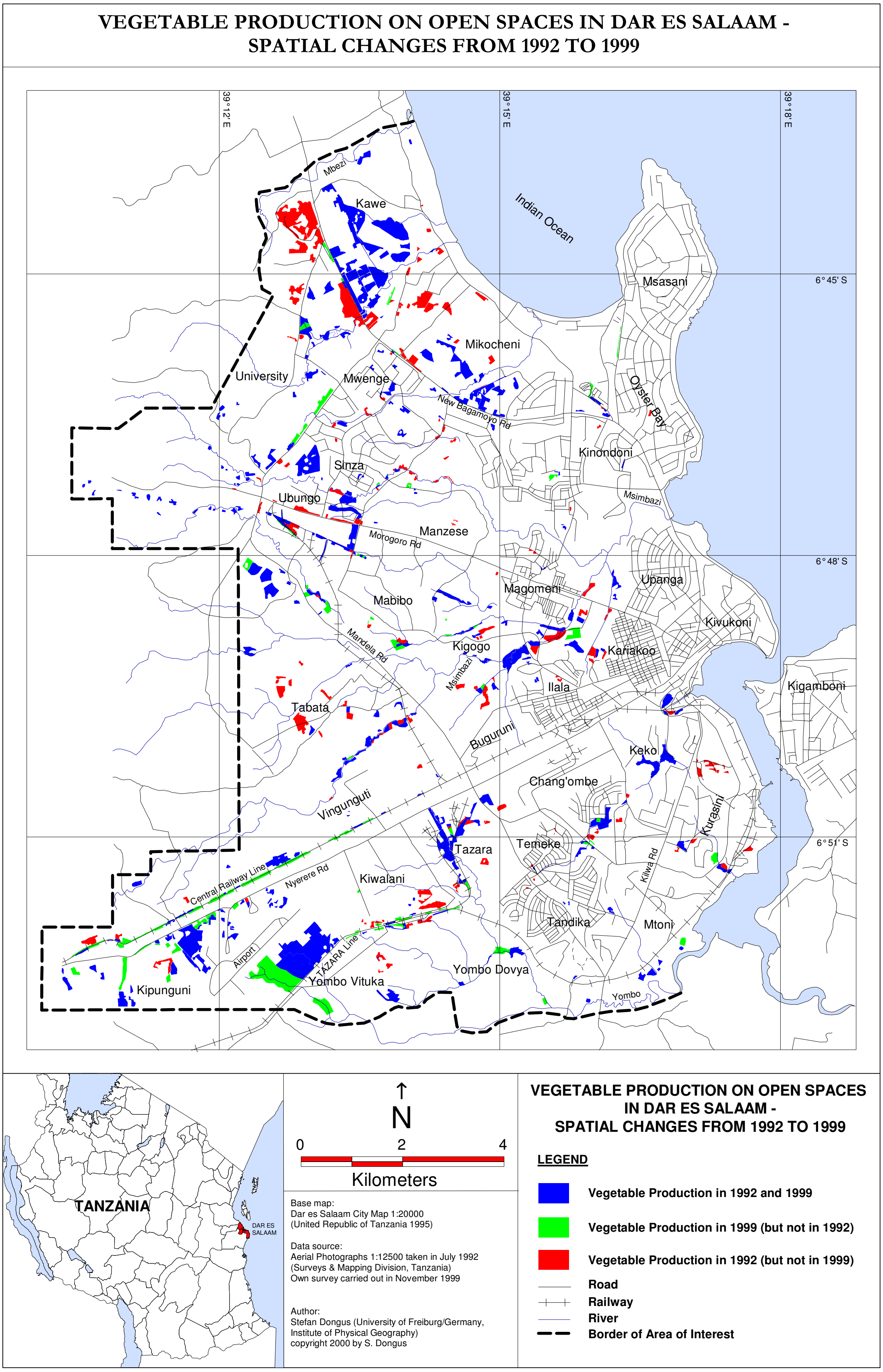

Figure 1.10: Map of vegetable production on open spaces in Dar es Salaam showing spatial changes from 1992 to 1999

Source: Dongus (2001)

Urbanisation also seems to shift the proportion of *Anopheles* biting indoors and outdoors towards the latter (Geissbühler et al. 2007a), and to cause them to adapt to polluted water as larval habitats (Sattler et al. 2005). It thus alters the transmission dynamics of malaria (Harpham & Tanner 1995). Urban malaria is characterised by a much greater heterogeneity than rural malaria, owing to the dynamic demographic and environmental conditions (Keiser et al. 2004, Robert et al. 2003). Until recently, urban development was generally believed to prevent vector breeding, and hence malaria transmission. Most cities in Africa are struggling to cope with the pace and the extent of urbanisation. As a result, many of these have only inadequate water supply and sanitation infrastructure, which in turn facilitates the creation of breeding sites for malaria-transmitting mosquitoes (Keiser et al. 2004, Knudsen & Slooff 1992). Though anopheline species density and the likelihood of malaria transmission is much lower in urban areas compared to periurban and particularly rural areas (Robert et al. 2003), malaria transmission in urban and periurban settings is a significant problem (Granja et al. 1998, Imbert et al. 1997, Trape et al. 1993).

Urban environments may increase malaria transmission, e.g. vegetation within the city and urban farming, which often provides ample aquatic habitats for mosquitoes. Increases in human activity may increase breeding opportunities for mosquitoes through the enhancement of shallow bodies of water and through an increase in the number of artificial water collection reservoirs, e.g. for irrigation (Robert et al. 2003). In Kampala, Uganda, malaria was strongly associated with proximity of residence to potential mosquito breeding sites (Staedke et al. 2003). Results from Keating et al. (2003) for two Kenyan cities revealed that most larval sites were human made, with the highest numbers of aquatic habitats observed in unplanned, poorly drained strata. Household density was a significant factor affecting the abundance of potential larval sites. In Dar es Salaam, *Anopheles* breeding sites have been comprehensively mapped and characterised by Sattler et al. (2005) (Figure 1.11).

1.7 Urban agriculture and malaria

The impact of UA on malaria transmission intensity in cities is not fully understood. In Kumasi, Ghana, higher adult anopheline densities were found in urban areas with agriculture than in those without agriculture. However, these UA areas were located in inland valleys that might have more mosquitoes due to the local ecology (Afrane et al. 2004). In Accra, Ghana, proximity to irrigated, open-spaced, and commercial vegetable production possibly contributed to increased transmission (Klinkenberg et al. 2005), and could potentially play a role in malaria epidemiology (Klinkenberg et al. 2008). Other studies found that certain irrigation practices result in larger mosquito populations (Afrane et al. 2004, Briet et al. 2003, Dolo et al. 2004, Ijumba & Lindsay 2001), but these do not necessarily lead to higher transmission levels (Dolo et al. 2004, Ijumba & Lindsay 2001). In Bouaké, Côte d'Ivoire, Dossou-yovo et al. (1994, 1998) found high anopheline densities but low sporozoite rates in areas bordering rice fields, concluding that rice cultivation did not seem to have modified malaria transmission notably. Robert et al. (1998) concluded from a study on market garden wells in Dakar, Senegal, that although wells served as breeding grounds for anophelines, other sites were more important in sustaining the mosquito population. In Dar es Salaam, Wang et al. (2006) found that having a small urban agricultural land or a garden near the living compound was not associated with malaria infection, but these surveys were conducted after a long phase of drought, when malaria prevalence was exceptionally low. The exact role of UA in malaria transmission thus remains unclear and needs further investigation (Afrane et al. 2004, Wang et al. 2006).

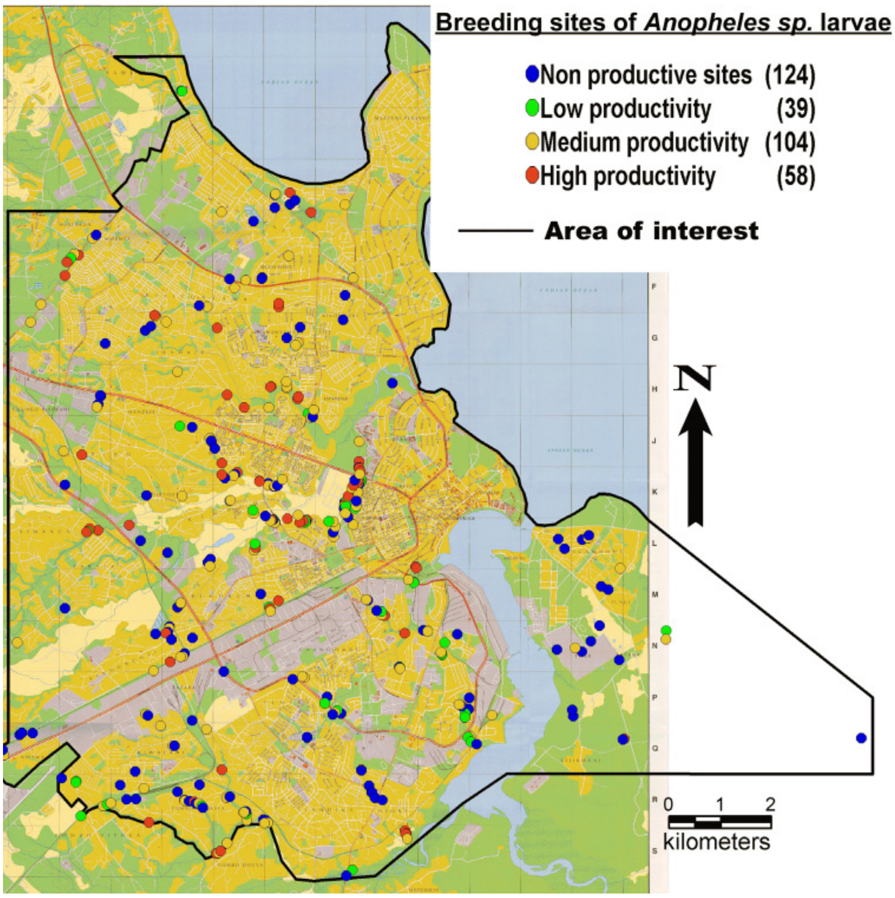

Figure 1.11: Breeding sites of *Anopheles* larvae in Dar es Salaam

Source: Sattler et al. (2005)

A variety of studies found UA creating breeding sites for anophelines (Afrane et al. 2004, Klinkenberg et al. 2008, Matthys et al. 2006, Trape & Zoulani 1987). On the other hand, a study in two Kenyan cities found no association between household level farming and vector breeding sites (Keating et al. 2004). Experiences in large scale rice irrigation schemes in Mali showed the types and the density of breeding sites varied depending on the rice growing stages. Therefore, water management such as intermittent irrigation as well as the adaptation of farming practices may significantly reduce the number of breeding sites in rice fields (Keiser et al. 2002, Klinkenberg et al. 2003, van der Hoek et al. 2001). In Dar es Salaam, Sattler et al. (2005) found that where the groundwater table was high (Figure 1.12), seedbeds with little ridges tilled for growing plants with furrows dug between the ridges (matuta) often contained shallow pools with Anopheles larvae. Rice fields, shallow wells and irrigation channels were also found to be very productive. However, malaria transmission in Dar es Salaam seems to be primarily associated with clusters of poorly drained and periurban areas, which often coincide with agricultural land use (Castro et al. 2004, Sattler et al. 2005). Anopheles breeding sites can thus be found in all kinds of urban land uses, agricultural or not, and it remains unclear whether agricultural land use or rather geographical factors such as topography and hydrology increase malaria transmission in urban areas. Recent evidence suggests the latter are more important (Jacob et al. 2005).

1.8 Malaria Control in Dar es Salaam

Dar es Salaam has a long history in malaria control, starting more than 100 years ago in the German colonial era (Clyde 1961, Mukabana et al. 2006). Since then, a variety of techniques were used to control malaria in the city for many decades, with considerable success (Castro et al. 2004). The main intervention adopted under German colonial rule was the use of quinine for treatment and individual prophylaxis (Ollwig 1903). Larval control of mosquitoes, particularly environmental management, played an important role in malaria control in Dar es Salaam for much of the 20th century (Mukabana et al. 2006). In 1913, the Germans issued an ordinance for mosquito extermination that provided legal sanction for the destruction of ponds, tins and other sources of standing water. Interventions during that time included oiling of water bodies, indoor house spraying with pyrethrum, and drain construction, resulting in a reduction in the mosquito population in the city of approximately 90% (Castro et al. 2004, Kilama 1991). Interventions under British rule after the First World War included drainage, straightening of streams, and oiling of puddles. Indoor residual spraying with DDT started in

1946 (Clyde 1962). When chloroquine was introduced after the Second World War, it soon became the drug of choice for malaria treatment. Resulting successes, especially due to DDT and chloroquine, diverted attention away from other interventions (Castro et al. 2004, Kilama 1994).

Figure 1.12: *Anopheles* breeding site in agriculturally used lowland area with standing ground water, Kurasini ward

Picture: Dongus 2005

In 1972, due to economic and political reasons, chemotherapy was the only anti-malaria intervention left in place. As a result, the density of *Anopheles* mosquitoes started to increase again (Kilama & Kihamia 1991). In 1983, malaria control policies in Tanzania were reformulated, re-emphasising the combination of interventions, including vector control, chemotherapy, and monitoring of drug resistance. Starting in 1988, the City of Dar es Salaam collaborated with the Japan International Cooperation Agency (JICA), focussing on vector control, promoting people's increased awareness of malaria and involving communities in environmental management activities (Castro et al. 2004, Mukabana et al. 2006). Despite some successes such as the rehabilitation of drainage infrastructure, this programme did not achieve sustainability and ended in 1996. Main reasons for this are considered to be insufficiently developed local ownership and capacity (Mukabana et al. 2006). Nevertheless, larval vector control is considered to be a feasible option in urban settings such as Dar es Salaam, as breeding sites for malaria vectors are limited, identifiable, and most importantly, accessible (Castro et al. 2004).

The Dar es Salaam Urban Malaria Control Programme

The ten-year Dar es Salaam Urban Health Project (DUHP) that started in 1990 (Wyss et al. 2000) has considerably strengthened healthcare and public health infrastructure within the city through a decentralised health system (Mtasiwa et al. 2003), creating a favourable environment for delivering community-based vector control interventions (Mukabana et al. 2006). These conditions finally resulted in the initiation of the current Dar es Salaam Urban Malaria Control Programme (UMCP) in 2002, when the Ilala Municipal Council independently planned, funded and implemented a community-based mosquito surveillance programme. The actual operational start of the UMCP followed in 2004, when the programme was scaled up to 15 of the 73 wards of Dar es Salaam, covering an area of 56 km². With support from national and international academic partners (Mukabana et al. 2006), the UMCP became the first community-based larviciding programme in modern Africa, managed and coordinated under the leadership of the City Medical Officer of Health. The Dar es Salaam City Medical Office of Health, which was established along with the DUHP, reports to the Ministry of Health for all technical issues and hence maintains strong interrelations with the Tanzania National Malaria Control Programme (NMCP) (Mtasiwa et al. 2004: 55).

The aim of the current Dar es Salaam UMCP is to control aquatic-stage mosquitoes using community-based resource persons (CORPs), and to evaluate the effectiveness of this intervention. The programme of work of the UMCP is part of the National Malaria Control Programme, which comprises vector control, improved malaria case management, malaria prevention in pregnancy, epidemic management and strengthening of systems for delivering and managing these interventions (Tanzanian Ministry of Health & World Health Organization 2004). All UMCP activities are fully integrated into the decentralised administrative system in Dar es Salaam, thus operating on all five administrative levels of the city: the city council, municipalities, wards, neighbourhoods referred to as *mitaa* in Kiswahili (singular *mtaa*, meaning literally street) and more than 3000 ten-cell-units. The main tasks on the four upper levels are project management and supervision, whereas the actual monitoring, mosquito larval surveillance and control is organised and implemented at the level of the smallest administrative units, the so-called ten-cell-units (TCUs) (Castro et al. 2004, Mukabana et al. 2006). The field-based activities of the UMCP are implemented by CORPs to whom specific responsibilities and target areas are allocated. The CORPs are volunteers receiving a small remuneration of ca. USD 2.5 per working day, and are usually members of the community they are working in. CORPs are appointed and managed through local administrative leaders on neighbourhood level. One group of CORPs is responsible for larval surveillance in terms of monitoring and documenting the larval habitats of mosquitoes in every TCU in weekly intervals. The other group of CORPs is responsible for applying biological larvicide (*Bacillus thuringiensis* var. *israelensis*, BTI) where necessary, on the day after the visit of the surveillance CORPs (Figure 1.13) (Fillinger et al. 2008, Mukabana et al. 2006, Vanek et al. 2006). The UMCP activities are described in more detail in chapter 5 & 6.

Figure 1.13: Activities of UMCP field staff (CORPs)

1 – Larval surveillance; 2 – Manual larviciding using BTI granules; 3 – Larviciding of larger water bodies with powered granule blowers; 4 – BTI granules. Pictures: Dongus 2006/2007

2 AIMS AND OBJECTIVES

The overall aim of this study was to contribute to a better understanding of the importance of urban agricultural land use in the context of environmental malaria control in urban SSA, and identifying potential mitigation options, by using a transdisciplinary approach.

In order to achieve this aim, the following four single objectives were defined:

1) To establish an agricultural database denoting the location, extent and features of urban agricultural areas, and to assess the spatio-temporal dynamics of urban agricultural land use in Dar es Salaam, by means of Geographical Information Systems (GIS)

2) To establish a spatial reference system for the UMCP intervention area by creating an integrated and scalable participatory mapping procedure that enables (i) linking the agricultural GIS database to all UMCP databases, and (ii) community-based environmental malaria control coverage without spatial gaps

3) To investigate how different urban agricultural characteristics as well as underlying geographical features are related to the presence of malaria vector mosquito larvae in Dar es Salaam

4) To explore to what extent the UMCP contributes to resilience-building processes in terms of mitigating malaria risk caused by breeding sites of malaria vectors

3 METHODOLOGY

The research approach used was a combination of natural and social scientific approaches, and included knowledge and capacities of stakeholders in the UMCP context of Dar es Salaam, with the goal of contributing to the mitigation of malaria risk in Dar es Salaam. This operational mixed methods research with a focus on quantitative physical geographic approaches but also including qualitative methods can be regarded as "transdisciplinary research" as defined by the Swiss NCCR North-South[6] (Hurni et al. 2004). The following paragraphs give an overview of the methods and data analysis approaches used. Detailed descriptions are included in the respective chapters.

3.1 Quantitative methods

Quantitative methods used in this study comprised:

- Participatory mapping of Ten-Cell-Unit boundaries – based on field work together with UMCP field staff, using printouts of aerial images for marking the respective area boundaries
- Cross-sectional mapping of agricultural areas – based on field work together with UMCP field staff, using printouts of aerial images for marking the respective area boundaries
- Questionnaire survey with farmers – using a set of closed questions (Appendix 2)

3.2 Qualitative methods

Qualitative methods used in this study comprised:

- Semi-structured key informant interviews and Focus Group Discussions with interview guidelines – held in Kiswahili language

[6] Transdisciplinary research is defined as "research that integrates the social and natural sciences in a common approach, and includes non-scientific knowledge systems in a participatory and interactive process to improve societal practices" (Hurni et al. 2004: 14).

3.3 Data analysis approaches

Data analysis approaches used in this study comprised:

- Creation of GIS database – digitising results of mapping activities and questionnaire survey using MapInfo[7] software; visual analysis of results using MapInfo and ArcGIS[8] software
- Statistical data analysis using STATA[9] software
- Content analysis of the English transcriptions of interviews and Focus Group Discussions using MAXQDA[10] software

3.4 Theoretical framework: Risk, Resilience and Threat

The theoretical framework guiding the study design as well as the data analysis was based on the concepts of risk, resilience and threat. These normative concepts "mean different things to different people" (Obrist 2005), and represent values and goals of those who define them. Furthermore, they are embedded in larger social, economic and political contexts (Obrist 2005). This chapter explains the meanings of these concepts, and how they were applied in the context of this study.

Blaikie et al. (1994) define risk as a function of threat (also referred to as hazard) and vulnerability: *Risk = Threat x Vulnerability*. This concept guided research for this study by suggesting that in order to gain a comprehensive understanding of factors related to malaria *risk*, it was necessary to focus on two components: (i) malaria *threat* that people are exposed to[11], and (ii) *vulnerability* of people to this threat. This distinction provided an ideal basis for integrating the different scientific approaches in the context of this study. While physical geography avails of suitable approaches to investigate *threat*, social sciences provided the frameworks needed for research on *vulnerability.*

[7] Version 7.0 Professional, MapInfo Corporation, One Global View, Troy, New York 12180
[8] Version 9.2, ESRI, Redlands, California, USA
[9] Version 9.0, Stata Corporation, College Station, Texas, USA
[10] Version 2, VERBI Software, Marburg, Germany
[11] In this study, preference is given to the use of the term *threat*, synonymous to the definition of *hazard* by Blaikie et al. (1994)

Natural hazards such as earthquakes or floods are typical examples of *threats*. In the context of our study, malaria *threat* refers to presence of breeding sites for malaria vectors. This threat is in the centre of attention in chapters 5-7. Whether this threat also poses a *risk* to people, by having a negative impact on their health and well-being, depends on their *vulnerability*. People are *vulnerable* to a threat if they are exposed to it and lack the adequate means to cope with it (Chambers 1989). Risk is not existent in case of an occurring threat to which the concerned society is not vulnerable (Blaikie et al. 1994, Wisner et al. 2004). Far more people are vulnerable towards their "normal" living conditions, which malaria is often a part of, than towards extraordinary events (Obrist 2005). Unless stated otherwise, we define malaria *risk* as the probability of being infected with malaria, and the potential for adverse events resulting from this infection.

However, instead of vulnerability, this study focussed on aspects of *social resilience*. Resilience – like vulnerability – is conceptually linked to hazard and risk. To a certain extent it can be seen as the opposite of vulnerability. However, according to Obrist et al. (2010b), it implies characteristics that go beyond this mere inverse relation. It draws attention to solutions rather than problems. Resilience is now often seen as a precondition for sustainability; however, little is known about what enhances resilience. "Resilience thinking invokes a positive and prospective view: it directs attention to the ability of people and social-ecological systems to positively adjust to change, risk and adversity" (Obrist et al. 2010b). Resilience is not only of analytical interest in terms of the identification and examination of patterns in problems and potentials of sustainable development, but also a practical concept for the identification of pathways to concrete mitigation of non-sustainable development (Obrist 2005). For these reasons, the resilience concept was favored over vulnerability.

This change was in line with current scientific discourse, which is increasingly shifting from vulnerability to resilience. Within the Swiss NCCR North-South, this development has led to the initiation of a 'Transversal Package Project' titled 'From Vulnerability to Resilience: Assessing the potential and limitation of a new conceptual approach for pathways to sustainable development"[12]. In the frame of this project, Obrist et al. (2010b) developed the

[12] The ideas presented in this article were developed within the 'Swiss National Centre for Competence in Research (NCCR) North South' funded Transversal Package Project (TPP) "From Vulnerability to Resilience" (/www.nccr-north-south.unibe.ch). The aim of the TPP was to identify commonalities and differences in various strands of resilience research which had developed independently in ecology, development psychology and development studies (Sustainable Livelihood

'Social Resilience' framework. For the first time, this framework conceptualises resilience in a way that makes it applicable in the field of development studies. The Social Resilience framework draws on ecological (Carpenter et al. 2001, Folke et al. 2002, Holling 1973), psychological (Luthar 2003, Masten 2001) and socio-anthropological approaches (Bourdieu 1984, 1986), as well as the Sustainable Livelihood approach (DFID 2000). Social resilience is defined as "the capacity of social actors to access capitals in order to not only cope with and adjust to adverse conditions (reactive capacity), but search for and create options (proactive capacity) and thus develop increased competence (positive outcome) in dealing with threats". Social resilience is multi-layered and built by actors on various levels which are relevant to the threat (Obrist et al. 2010b).

The concept of social resilience was applied in our study, as it was considered to be the ideal framework for the social scientific part of the work as presented in chapter 8. The definition was adjusted to the study context as follows: *social resilience to malaria* is defined as "social actors' capacities to not only cope with and adjust to malaria threat, but search for and create options and thus develop increased competence in mitigating malaria threat by eliminating mosquito breeding sites, with the positive outcome of not getting ill with malaria". Figure 3.1 visualises the simplified framework that was the theoretical basis for this study, outlining that *threat* and *resilience* were investigated in order to gain a more comprehensive understanding of factors related to malaria *risk*.

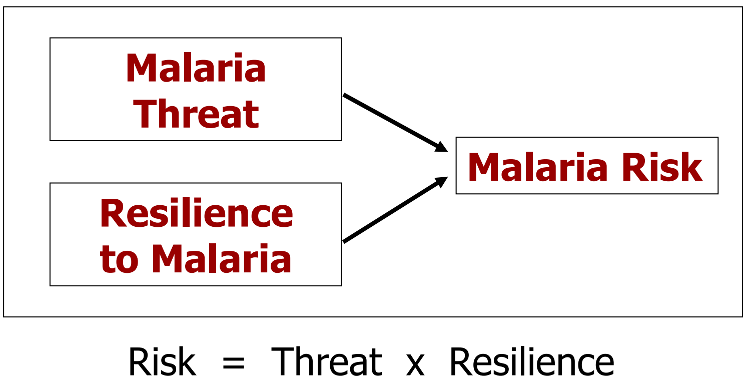

Figure 3.1: Theoretical Framework

Source: Dongus, based on Blaikie et al. (1994)

approaches) and to link them with social and cultural theory in a new framework for studying social resilience in context.

3.5 Ethics

This study did not involve human subjects. Research clearance for the UMCP programme was obtained from the Medical Research Coordination Committee of the National Institute of Medical Research in Tanzania (NIMR/HQ/R.8a/Vol. IX/279). Stefan Dongus obtained a research permit from the Tanzanian Commission of Science and Technology (No. 2005-123-NA-2004-163 and No. 2006-115-ER-2004-163). In order to achieve community consent and before starting any field work, the stakeholders and community leaders at the respective local government units were contacted. The goals of the activity were explained, and the survey team was introduced. All responsible UMCP staff members were present in such meetings.

The following five chapters[13] investigate the importance of urban agricultural land use in the context of environmental malaria control in urban sub-Saharan Africa, and potential mitigation options. First, results from a GIS-supported agricultural survey are presented that illustrate the extent and dynamics of UA in Dar es Salaam. Second, the development and validation of a participatory mapping method that was necessary for linking agricultural data with routinely collected larval data of the UMCP is described. Third, the function of the participatory mapping method as an essential contribution towards the optimisation of UMCP operational procedures is highlighted. Fourth, the role of urban agricultural and other factors with regard to provision of suitable mosquito breeding sites is discussed based on results from statistical analysis. Fifth, resilience-building processes on various programme levels in the context of the UMCP are analysed by applying the Social Resilience Framework.

[13] This is a “cumulative” dissertation, consisting of individual manuscripts that have already been published, or will be published soon. Where the use of terms deviates from the definitions given in this introductory chapter, the terms will be defined in the respective chapters.

4 DYNAMICS AND SUSTAINABILITY OF URBAN AGRICULTURE: EXAMPLES FROM SUB-SAHARAN AFRICA

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4.1 Abstract

Introduction

Urban agriculture can have many different expressions varying from backyard gardening to poultry and livestock farming. This article is focussing on crop production on larger open spaces in cities of sub-Saharan Africa (SSA) and investigates the sustainability and dynamics of this type of land use, which is common on undeveloped plots particularly in lowlands, such as in inland valleys, or along urban streams or drains.

Methods

An adapted version of the Framework for Evaluating Sustainable Land Management (FESLM) developed by the Food and Agriculture Organization of the United Nations (FAO) was used to assess the sustainability of urban agriculture. As an example for dynamics, the spatio-temporal changes of open space agriculture in Dar es Salaam, Tanzania, are analyzed for the period from 1992 to 2005, and compared with data from other cities.

Results and Discussion

Crop production on urban open spaces appears as a market-driven, highly productive and profitable phenomenon. However, it is often constrained by tenure insecurity and non-agricultural land demands. Also the common use of polluted water limits the official support of irrigated urban farming. However, despite these constraints, the phenomenon of urban farming appears persistent and resilient to its changing environment, although individual farmers might have to shift to other sites when their plots are needed for construction.

Conclusions

Open space vegetable production in urban areas is a dynamic, viable and largely sustainable livelihood strategy, especially for poor urban dwellers. Spatio-temporal analysis shows that it is not a short-lived or transitional phenomenon – probably as long as it can maintain its comparative market advantage. However, its informal nature and resulting lack of political recognition need to be addressed.

4.2 Introduction

Cities in sub-Saharan Africa (SSA) are growing fast. With 3.7%, the current annual urban growth rate is almost double the world-wide average and by 2030, half of Africa's population will be urban (UN 2008b). Apart from its socioeconomic implications, this rapid urbanization is posing major challenges to environmental protection and the supply of adequate shelter, food, water and sanitation (Hardoy et al. 2001, UNFPA 2007). A response to urban food demands is urban and peri-urban agriculture, which can be broadly defined as the production, processing and distribution of foodstuffs from crop and animal production within and around urban areas (Mougeot 2000b). Although the terms 'urban agriculture' and 'peri-urban agriculture' are often used synonymously, this paper only refers to urban agriculture, i.e. farming within cities, unless otherwise stated.

Agriculture has a longstanding indigenous tradition in many African urban areas (Harris 1998, La Anyane 1963), but has usually been considered a quintessentially rural activity. 'Urban agriculture' may therefore appear to be an oxymoron (Smit et al. 1996). However, urban agriculture is a widely practised phenomenon involving more than 20 million people in West Africa alone, and 800 million worldwide (Drechsel et al. 2006, Smit et al. 1996). Despite its significance and long history, urban agriculture receives a significantly higher recognition by authorities in the developed world than for example in Africa.

Urban farming systems can have a variety of expressions which can be classified according to different criteria. A basic differentiation among urban crop farming in Africa is to distinguish between (i) open space production of high-value products on undeveloped urban land, and (ii) mostly subsistence gardening in backyards (Table 4.1). In this article, we will focus on the first category, and in particular on the widely distributed system of irrigated urban vegetable production. According to a survey of the International Water Management Institute (IWMI) within 14 larger African cities, typical areas under open space irrigation range from 20 to 650 ha per city (Drechsel et al. 2006).

Table 4.1: Major categories of urban production in Africa

Farming systems	Crops and consumer	Urban locations
Open space production (off-plot farming)	Typically (but not only) irrigated vegetables and herbs predominantly for market sale (irrigation is year-round or only in the dry season) but in parts of Eastern and Southern Africa also for home consumption	Open areas along streams and drains, unused lowlands, urban inland valleys
	Rain-fed cereals (often maize) for home consumption and/or market sale	Unused plots, public open spaces, utility service areas
Backyard gardening (on-plot farming)	Cereals, vegetables, fruits, plantain, predominantly for home consumption	On the plots around houses, like in backyards

Source: Drechsel et al. (2006); Mbiba (2000)

These areas can comprise public land along roads, power lines, drains and streams, but also privately or institutionally owned land. In many cases, public and private landowners tolerate urban farming, for example as protection against other forms of encroachment (Drechsel et al. 2006). Open spaces are usually cultivated by groups of farmers, not necessarily working together (Jacobi et al. 2000a) and often consisting of rural migrants (Drechsel et al. 2006). The dominating crops are vegetables. Other crops grown include rice, fruit, cereals, root crops, leguminous crops and oilseed crops depending on local demand (Dongus 2001). Especially if irrigated, open space agriculture allows very competitive profits provided farmers are ready to cope with a variety of risks which are usually peculiar to urban farming. Such risks comprise tenure insecurity, lack of subsidies, official support or extension services, high land competition in particular with non-agricultural land use, poor soils without options for fallowing, as well as possible prosecution due to illegal land or water use. This makes urban farming on open spaces rather special among the various farming systems in Africa.

Market proximity allows close observation of price developments as well as reduced transport costs. The choice of crops grown is depending on regional diets but also reflecting increasing demands for ‘fast food’ and other ‘urban’ diets, especially in multi-cultural city environments. The resulting diversity of food and income resources is a major buffer against vulnerability in urban environments with poor economic development (Drescher et al. 2006). Depending on supply and demand, market prices vary frequently and urban farmers might change crops from month to month in order to grow the most profitable ones (Danso & Drechsel 2003). The built environment, however, limits the choice of farming sites, as open land gets scarce towards the urban centres. This argument is often used by local authorities to question the viability and sustainability of this farming system, and thus the need to address it. Especially valuable agricultural sites are those with water access because profits are highest in the dry season when supply is limited. Thus, unused governmental plots along streams or in lowlands with a shallow groundwater table are preferred.

This article discusses the sustainability and dynamics of crop production on urban open spaces. Sustainability is assessed by applying the Framework for Evaluating Sustainable Land Management (FESLM) developed by the FAO (Smyth & Dumanski 1993), which considers indicators like the creation of employment, efficient resource utilization and empowered communities, as well as possible trade-offs and negative perceptions. This framework thus accounts for the importance of extending the traditional cost-benefit-analysis concept to recognize also intangible and non-quantifiable values and impacts (Nugent 1999). Within this framework, several examples from existing literature are discussed. Furthermore, dynamics of open space production regarding spatio-temporal changes are illustrated by so far unpublished data from the cities of Dar es Salaam, Accra and Freetown.

4.3 Methods

The city of Dar es Salaam, Tanzania, was chosen as our main example to illustrate the dynamics of crop production on open spaces. Dynamics in this context refer to spatio-temporal changes such as growth or decrease in size over a given period of time. To our knowledge, Dar es Salaam is the city with the most comprehensive record of spatial data regarding urban crop production in SSA. For comparison we considered unpublished and published data from three other cities in West and East Africa (Accra, Freetown and Khartoum).

From 1990 until 2008, the growth rate of the urban population in Tanzania has constantly been between four and five percent (UN 2008b). The challenges coming with this rapid growth can be compared to those of other cities in Africa. The study area in Dar es Salaam (total city population: 3 million) comprises 14 urban "wards" with more than half a million inhabitants (National Bureau of Statistics 2003). Within this area, all open spaces with agricultural production have been mapped for three points in time (1992, 1999 and 2005). The methodology used for 1992 and 1999 was a combination of aerial photographs' analysis and field-based surveys (Dongus 2000, 2001). The 2005 update was based on field-based surveys (Dongus et al. 2007) and supported by visual interpretation of Google Earth™ imagery made available in July 2008. All three mapping phases have a common area of 42 km^2 showing the whole range of land uses as well as geographic and socio-economic characteristics that can be found in urban Dar es Salaam. All areas with crop production larger than 1000m^2 located within this study area were included in the survey.

In order to assess the sustainability of urban agriculture, the FAO Framework for Evaluating Sustainable Land Management (FESLM) was used (Smyth & Dumanski 1993). According to the FESLM, sustainable land management (1) maintains or enhances production/services, (2) reduces the level of production risk, (3) protects the potential of natural resources and prevents degradation of soil and water quality, is (4) economically viable and (5) socially acceptable. The analysis followed these five "pillars of sustainability" (Smyth & Dumanski 1993) that allow highlighting and evaluating major characteristics of the farming system. The specific nature of urban vs. rural agriculture makes it necessary to slightly extend the original FESLM framework (Table 4.2). For each of the five pillars, evidence from existing literature is presented and discussed. Due to availability of suitable data, the majority of the examples for this part of the article are taken from the West African context.

Table 4.2: The five pillars defining sustainability in FAO's FESLM for rural farming and their adaptation to irrigated urban agriculture

Pillar	Rural agriculture	Urban agriculture (off-plot)
1	Maintain or enhance productivity	Maintain or enhance productivity
2	Reduce production risks	Reduce production and eviction risks
3	Safeguard the environment	Safeguard human and environmental health
4	Be economically viable	Be economically viable
5	Be socially acceptable	Be socially and politically acceptable

Source: modified after Smyth and Dumanski (1993)

4.4 Results and Discussion

Dynamics of the urban agricultural phenomenon

Figure 4.1 shows a map of the central part of urban Dar es Salaam, and the areas used for crop production on open spaces in the years 1992, 1999 and 2005 within the study area. From 1992 until 2005, urban farmland disappeared on three of four sites, but completely re-emerged while it remained constant on one of four. In other words, of the about 4% of the study area with farms larger than $1000m^2$, one percent has continuously been used for this kind of urban agriculture (areas marked in dark green). During the same period, cultivated open spaces covering 3.2% of the area have newly emerged (light green). This is slightly more than the 3.1% of the study area that has been under production at some point in time since 1992, but was not in agricultural use anymore in 2005 (red). All in all, slightly more open spaces were cultivated in Dar es Salaam's central urban area in 2005 (4.2% of the study area) compared to 1992 (3.8%), i.e. there was no decrease in farming. This percentage is about the same proportion of land that was found to be under open space cultivation in the whole urban area of Dar es Salaam in 1992 and 1999 showing that the study area appears to be representative (Dongus 2000).

The overall amount of cultivated open spaces has basically remained the same during the past two decades, whereas the locations of the agricultural areas have changed considerably. Only 23% of the area under cultivation in 2005 has been "stationary" throughout, most of it (73%) located along rivers, and therefore in lowland areas prone to flooding and not used for construction. Most of the newly emerged areas (78%) can be found along rivers as well, and another 6% along railway lines where any kind of construction is prohibited. Parts of this area have already been used agriculturally in 1992, but the density of use has increased significantly. The main reasons why other agricultural areas have in turn disappeared are construction of houses or industrial use. This also applied to some areas next to rivers which gave way to informal settlements, such as in Mchikichini or Keko.

The results illustrate the highly dynamic and adaptable nature of agriculture in the urban environment. The resilient character of urban farming in SSA becomes obvious by its ability to persist the high non-agricultural pressure on land. The fact that urban residents continue to practice urban agriculture is illustrated by its permanent presence and magnitude[14]. The results echo findings from Khartoum where over the last 50 years urban farming has always been an important land use with an average increase of farmland by 172 ha per year (Luedeling et al. 2007). The Khartoum study considered city growth and the increase of the city area in its assessment. Where this is not done, it is possible that the analysis will show a

[14] In general, the extent of urban agricultural land use is even higher than reported here, as several hundred backyard gardens smaller than 1000 m^2 were not included in the open-space surveys.

shrinking area of open spaces. A comparison of different land use categories in the same inner part of Accra, Ghana, between 2001 and 2008, showed a general decrease in open spaces and urban farm areas by over 50% from about 6 to 3 km^2 (Forkuor, unpublished). The analysis did not consider that in less densely populated city areas vacant plots are continuously transformed into farmland. Of particular importance for the final result is the area of unused land in the city or study area boundary. In Freetown, Sierra Leon*e*, for example, the build-up area comprised in 1974 only about 10% of the City Council Area. With increasing urbanization, also agricultural land use increased especially between 1986 and 2000 by about 43% (from 3 200 ha to 4 600 ha). The analysis found that in the same period about 882 ha (27%) of agricultural lands was converted to residential purposes mostly at the urban fringes. On the other hand, 14% of forest in the urban area (1822 ha) was found to have been converted to agricultural land (Forkuor & Cofie, unpublished).

Sustainability of the urban agricultural phenomenon

The Dar es Salaam, Khartoum and Freetown case studies showed the dynamic and resilience of the urban agricultural phenomenon. Although many farms change their location over time, other open areas – usually those unsuitable for housing or construction - have been under continuous cropping for the past 20 – 50 years as reported from West and East Africa (Dongus 2001, Drechsel et al. 2006, Luedeling et al. 2007, Obuobie et al. 2006). Interviews carried out by IWMI in Ghana showed that 80% of all urban open space farmers use the same piece of land all year round, and 70% had continuously cultivated their plots for more than 10-20 years. This is not only remarkable in a tropical context, which normally only supports shifting cultivation; but also because available urban soils can be of particularly disturbed, moist or poor nature. Along the West African coast, for example, where several of Africa's capitals and/or mega cities are located, urban farmers use beach sands of negligible inherent fertility and water holding capacity for high input market-oriented (and even export) vegetable production. Further inland, urban farming sites are often in more fertile lowlands, which are however often too moist for construction. The endurance of open space farming over decades seems to support the assumption that the system is sustainable in general. However, the FESLM with its 5 pillars allows a more differentiate analysis.

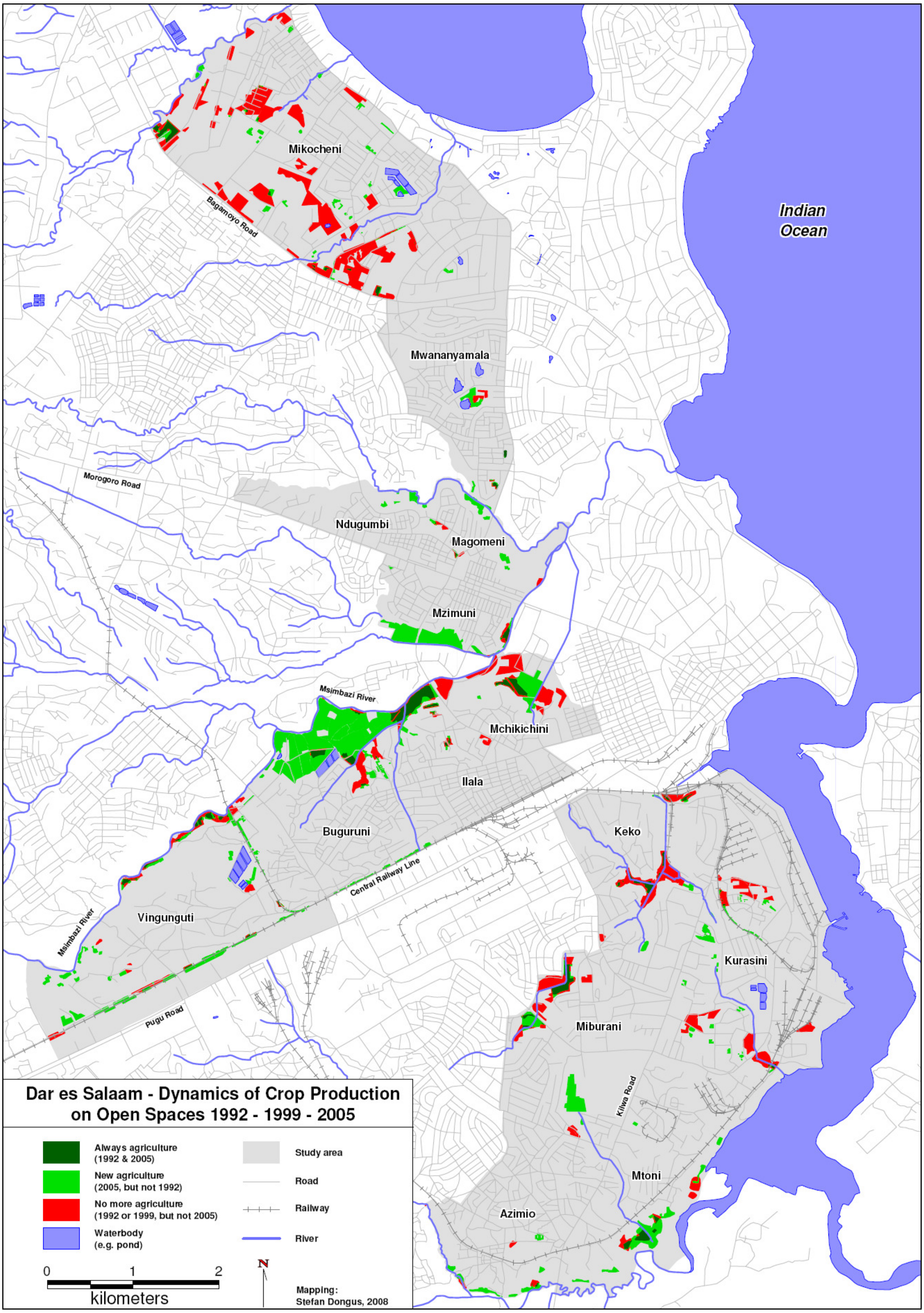

Figure 4.1: Spatio-temporal changes of crop production on urban open spaces in Dar es Salaam, Tanzania (1992 – 1999 – 2005)

Horizontal text labels: names of the 14 wards that constitute the study area. Mapping: S. Dongus

Pillar 1: Is urban crop production able to maintain or enhance land productivity?

Where irrigated, common urban cropping systems often consist of several crops per year, like for example nine lettuce harvests interrupted by one cabbage crop, all on the same beds, or six spring onion harvests interrupted by two cabbage crops. With every harvest, nutrients are exported, while fertility recovering fallow periods are short and only observed when market demand is too low for sufficient revenues. This might be in the rainy season when other urban farmers switch to maize production. Such intensive production requires high external inputs and soil protection to maintain productivity. This makes urban farming very input intensive and farmers perceptive to technology transfer and closed loop concepts. Indeed, different types of urban waste resources are used, from solid waste compost to sludge, wastewater and agro-industrial waste, making the system less dependent of fertilizer price fluctuations. Wherever available, urban vegetable farmers prefer cheap poultry manure, which releases nutrients sufficiently fast for vegetables with short growing periods.

Manure application rates can be especially high if soils are sandy, and frequent irrigation leaches the applied nutrients. Around Kumasi, Ghana, for example, poultry manure is applied over the year at a rate of about 20-50 tonnes per hectare on cabbage and about 50-100 tonnes per hectare on lettuce and spring onions. In the same area, mostly also industrial fertilizer is used on selected crops, like cabbage. Due to frequent irrigation, a vicious cycle of nutrient depletion (through harvest and leaching) and instant replenishment (through manure/fertilizer and partly wastewater irrigation) can be observed, which can lead to the accumulation of poorly leached phosphorous and temporary depletion of nitrogen and potassium (Drechsel et al. 2005). Although the efficiency of water and nutrient use might be far from perfect, the long record of continuous farming on the same sites is a clear indication of a system that can maintain its productivity.

Pillar 2: How does urban crop production cope with production and eviction risks?

Sufficient profits, which support the purchase of inputs and adoption of technologies – such as treadle or motor pumps, pesticides and fertilizers – reduce natural production risks. This is certainly a strong point of urban open-space farming (see pillar 4). The 'human' risk factor is more difficult. While market proximity supports urban farming, urban expansion constrains it. There are only a few examples in sub-Saharan Africa where open spaces are designated for urban agriculture, as any construction project normally has a stronger financial lobby than urban farming (van den Berg 2002). For example, Olofin and Tanko (2003) as well as Foeken and Mwangi (2000) describe that like in the Dar es Salaam case described above, many sites formerly available for urban agriculture in Kano, Nigeria, and Nairobi, Kenya, have disappeared. This is a common observation from Addis Ababa to Harare and Dakar due to unfavourable land use plans, and insecure or non-existent tenure arrangements (Endamana et al. 2003, Obuobie et al. 2003, Orchard et al. 1997). In Zambia, land use planning does not even provide for mixed land use. This implies that designated urban land can only be for residential use, and that farming is 'illegal' (Mubvami & Mushamba 2006).

Farmers cope with tenure insecurity through low investment, simple and movable technologies (watering cans) and the cultivation of short-duration crops for immediate cash return. In the case that farmers are expelled, they might move to another site in the vicinity or towards the peri-urban fringe. The Dar es Salaam example supports this theory, as the same amount of areas that disappeared has newly emerged somewhere else during the same period. However, it was not analysed if the same farmers moved to the new areas or if others took advantage of the reduced vegetable supply. In general, urban open space farming therefore resembles shifting cultivation in its dynamism, and also in terms of resilience through its ability to recover after disturbances with a spatial shift. Thus, the 'phenomenon' of urban farming persists while individual farmers might lose their plots, unless they are on sites that are too moist for or excluded from construction (like under power lines). But there are also institutional highlights, like in Dar es Salaam, where urban farming has been recognized in the city's strategic development plan (Mubvami & Mushamba 2006). The implementation of such plans seems to be limited though, and urban farming is still far from being truly integrated into urban planning in Dar es Salaam (Magigi 2008).

Pillar 3: Is urban crop production environmentally sound and does it not affect human health?

The need for continuous cropping on the same plots makes many urban farmers specialists in soil conservation. This applies in particular to irrigated vegetable production which provides a protective soil cover throughout the year and contributes to urban greening and biodiversity. However, irrigated urban farming has a stigma due to the common use of wastewater and pesticides which is likely to affect the environment as well as consumers' and farmers' health (Birley & Lock 1999). The status of urban agriculture in Harare, for example, has been guided by the public and official view that urban agriculture poses a threat to the environment, and research has attempted to establish the extent of the threat (e.g. malaria, hydrological issues, soil erosion, ecological changes and chemical pollution) (Mbiba 2000). Comparative studies in Ghana showed, however, that pollution from agricultural return flow is negligible vis-à-vis normal urban pollution (Obuobie et al. 2006). Detailed studies also showed that there is no clear evidence that irrigation in the city increases urban malaria although green open spaces can provide mosquito resting places and breeding sites if clean water is used (Klinkenberg et al. 2008, Klinkenberg et al. 2005). This also applies to green open spaces not used for farming. Preliminary results from a recent study in Dar es Salaam indicate that certain farming characteristics have the potential to impact the presence of breeding sites for malaria vectors, but that at the same time, underlying geographical and hydrological factors play a very important role (Dongus et al. in chapter 7).

There is however substantial evidence from East and West Africa that urban agriculture causes health risks through the common use of polluted water for crop irrigation (Cornish & Lawrence 2001, Drechsel et al. 2006). This risk is considered significantly more important for consumers than the one from pesticide use (Amoah et al. 2006). As consumers' awareness of related risks is generally low, there is little market demand and pressure for safer food. Reasons for such low awareness can be seen in educational constraints as well as the presence of many other significant health risks, such as lack of potable water, generally poor sanitation, low income, malaria or HIV. Authorities are trying to prevent the use of polluted water either through prosecution or the exploration of alternative farm land and safer water sources. In Benin, for example, the central government decided to allocate 400 ha of farmland with safer groundwater to the urban farmers of Cotonou, and in Accra, Ghana, they explored the possibility of safe groundwater supply on urban farming sites while the research community tested safer irrigation practices (Drechsel et al. 2006, Drechsel et al. 2008) in line with the Guidelines for Safe Wastewater Irrigation of the World Health Organization (WHO 2006). Once implemented, these options can help to reduce one of the most significant externalities of irrigated urban farming.

Pillar 4: Is urban crop production profitable?

A key sustainability criterion, at least from the farmers' perspective, is the cost-benefit ratio of their farming system. Market proximity allows urban farmers specialized on high-value crops to save on transport costs and to closely follow demand. This specialization gives them a significant income and provides cities with a reliable supply of perishable vegetables. Particularly during the dry (lean) season when supplies decline and prices increase, irrigated urban vegetable production is financially and socially profitable while in the bumper season not all produce might be sold (Gockowski et al. 2003, van Veenhuizen & Danso 2007).

A review of revenues from mixed vegetable production in open space urban agriculture showed that in many cases monthly incomes range between US$ 35 and 85 per farmer. These can go up to US$ 160 or more given larger space, extra labour and a more efficient water lifting device (e.g. motor pump) for irrigation (Table 4.3). In Dakar, Niang et al. (2006) showed that for lettuce only, revenues for farmers can reach US$ 213 to 236 per month. If farmers have water access and produce throughout the year, they have a good chance to pass the poverty line of US$ 1 per day, especially if other household members contribute their own incomes. Without water access, however, production might be limited to a few months and other income sources are required in the dry season.

Table 4.3: Literature review of monthly net income from irrigated mixed vegetable farming in West and East Africa (US$ per actual farm size)

City	Typical net monthly income per farm in US$[15]
Accra	40-57
Bamako	10- 300
Bangui	n.d. -320
Banjul	30 – n.d.
Bissau	24
Brazzaville	80-270
Cotonou	50-110
Dakar	40- 250
Dar Es Salaam	60
Freetown	10-50
Kumasi	35-160
Lagos	53-120
Lomé	30-300
Nairobi	10-163
Niamey	40
Ouagadougou	15-90
Takoradi	10-30
Yaoundé	34-67

Source: Drechsel et al. (2006)

An economic comparison of irrigated urban agriculture, dry-season irrigation in peri-urban areas and rainfed farming in rural areas was carried out in and around the city of Kumasi in

[15] Values reflect actual exchange rates. n.d.= not determined/reported.

Ghana (Danso et al. 2002). It was found that urban farmers on irrigated land earn about 2-3 times the income from traditional rainfed agriculture (Table 4.4).

Table 4.4: Comparison of revenue generated in rainfed and irrigated farming systems in and around Kumasi, Ghana

Location	Farming system	Typical farm size (ha)	Net revenue (US$)/ farm holding/year[16]
Rural/peri-urban	Rainfed maize or maize/cassava	0.5-0.9	200-450[17]
Peri-urban	Dry season vegetable irrigation *only* (garden eggs, pepper, okra, cabbage)	0.4-0.6	140-170
Peri-urban	Dry-season, irrigated vegetables and rainfed maize (or rainfed vegetables)	0.7-1.3	300-500[2]
Urban	All-year round irrigated vegetable farming (lettuce, cabbage, spring onions)	0.05-0.2	400-800

Source: Danso et al. (2002)

Moustier (2001) stresses that the income generated in urban agriculture should not only be compared with revenues from other land uses, but also alternative uses of capital and labour. Even if the total number of farmers is small compared to the total urban population, urban vegetable production is one of only a few stable sources of income for workers with limited qualifications. Compared with smallholder farming in formal irrigation schemes, irrigated urban agriculture shows lower investment costs, higher returns to investment and a shorter investment period. This makes urban farming especially attractive for farmers with little financial (start-up) capital, despite higher total returns in the formal vegetable production sector.

Pillar 5: Is urban crop production socially and politically accepted?

A feature of many African cities is their lateral growth with relatively low housing densities except in slum areas. This provides open space often used for farming. While backyard farming is a well-tolerated (private) feature in many cities, the situation can be different in other cities with high housing density or where agriculture is seen as an informal or rural activity that goes against the image of modern civilization and progress (van den Berg 2002). One of those cities where both constraints meet is Cairo. Cairo has not only limited space to

[16] The smaller figure refers to the smaller farm area, the larger one to the larger area
[17] For easier comparison, the assumption is that farmers sell all harvested crops. It is possible, however, that farmers consume a significant part of their maize and cassava harvest at home.

offer, it also tries actively to project an image attractive to its sensitive tourist industry. In Cairo, this is expressed in urban planning and "face-lifting" activities including the sanctioning of informal activities (Gertel & Samir 2000). In other cities, health authorities lobby against irrigated urban farming due to the use of polluted water sources (Mbiba 2000, Obuobie et al. 2006).

As most African cities face more significant urbanization-related challenges than "urban farming", like waste management, power and drinking water supply, it is not surprising if urban agriculture does not get much political attention. As reported from Southern, Eastern and Western Africa, it is usually ignored or tolerated without any significant restriction or support (Cissé et al. 2005, Foeken & Mwangi 2000, Mbiba 2000, Rogerson 1997). In some cases, one ministry might support urban farmers with extension services, while another arrests them for using polluted irrigation water (Obuobie et al. 2006).

Such contradictions or at best *laissez-faire* attitude keeps urban farming in a political vacuum, which does not help to address some of its major problems, such as lack of suitable land, low tenure security, theft of produce, and access to low-cost but safe water. In particular, lack of tenure security limits investment in farm infrastructure, such as fences, wells and water pumps (Bourque 2000, Ezedinma & Chukuezi 1999, Mbiba 2000, Mougeot 2000b). Investments, however, might not only be important for the farmer (e.g. in labour-saving irrigation infrastructure) but also society (e.g. in safer water sources or on-farm wastewater treatment ponds as currently tested in Ghana).

A common feature is that the benefits of urban agriculture for livelihoods, food security and the environment are more recognized on the international than on the local level. Therefore, the work of internationally funded agencies and networks to support local and regional recognition of urban agriculture appears to have been a crucial element in any progress observed. A major initiative is the International Network of Resource Centres on Urban Agriculture and Food Security (RUAF), which supports multi-stakeholder processes in Africa, Latin America and Asia via strategic focal points to catalyse the official recognition of urban agriculture (Dubbeling & Merzthal 2006). In March 2002, for example, a declaration was signed in Dakar by seven mayors and city councillors from West Africa in support of the development of the urban agricultural sector (Niang et al. 2002). In the same year, the Senegalese President promulgated a decree to develop and safeguard urban agriculture in

Senegal's Niayes and green areas of Dakar (Niang et al. 2006). In the Harare Declaration (29 August 2003), five Ministers of Local Government from East and Southern Africa called for the promotion of a shared vision of urban farming, and in Accra, a Vision Statement on Urban Agriculture in the city was signed (Obuobie et al. 2006). In addition, the experiences from Kampala and Dar es Salaam have shown that the integration of urban agricultural land use into urban planning is not only important, but also feasible, and that restrictive policies on urban agriculture are bound to be ineffective (Atukunda 2000, Kitilla & Mlambo 2001, Magigi 2008). Indeed, there is a need to formulate more diversified and regulatory policies that seek to actively manage the health and other risks related to urban farming through an integrated package of measures, with the involvement of the direct stakeholders in the analysis of problems and development of workable solutions. This is high on the agenda of RUAF and an important step towards lifting urban farming from an informal activity to official recognition and institutional sustainability.

4.5 Conclusions

Adapted to the urban context, the five pillars of the FAO framework for the evaluation of sustainable land management (FESLM) can be a useful guidance for assessing also the sustainability of urban farming. Crop production on open urban spaces in SSA appears to be a dynamic, viable and largely sustainable bright spot providing jobs and food for the cities. Despite rapid urbanization, this farming system is neither a declining nor a temporary phenomenon, as shown among others by the example of Dar es Salaam. Indeed, in many countries of SSA, urban farming shows a remarkable resistance against various constraints, and maintains its niche without external initiative or support. It takes advantage of market proximity, the high demand for perishable cash crops, and the common lack of refrigerated transport. Once these conditions change, its comparative advantage might decrease. This is so far, however, not the case.

In contrary, urban farming often bears more potential that could be tapped with appropriate institutional recognition and support, which would also help strengthening efforts to address its possible externalities affecting environment and health. Especially the need for safer irrigation water sources and/or irrigation practices is not only of high importance in SSA but in three of four cities in developing countries in general (Raschid-Sally & Jayakody 2008). It is thus important that policy makers recognize urban farming as a highly dynamic but lasting phenomenon with a high potential to support various development goals if it can be lifted it out of its informality, for example by zoning designated agricultural areas along streams, roads or power lines (buffer zones). This would be a milestone towards official support and more sustainability of this interesting farming system.

4.6 Acknowledgements

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5 PARTICIPATORY MAPPING OF TARGET AREAS TO ENABLE OPERATIONAL LARVAL SOURCE MANAGEMENT TO SUPPRESS MALARIA VECTOR MOSQUITOES IN DAR ES SALAAM, TANZANIA

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5.1 Abstract

Background

Half of the population of Africa will soon live in towns and cities where it can be protected from malaria by controlling aquatic stages of mosquitoes. Rigorous but affordable and scaleable methods for mapping and managing mosquito habitats are required to enable effective larval control in urban Africa.

Methods

A simple community-based mapping procedure that requires no electronic devices in the field was developed to facilitate routine larval surveillance in Dar es Salaam, Tanzania. The mapping procedure included (1) community-based development of sketch maps and (2) verification of sketch maps through technical teams using laminated aerial photographs in the field which were later digitized and analyzed using Geographical Information Systems (GIS).

Results

Three urban wards of Dar es Salaam were comprehensively mapped, covering an area of 16.8 km². Over thirty percent of this area were not included in preliminary community-based sketch mapping, mostly because they were areas that do not appear on local government residential lists. The use of aerial photographs and basic GIS allowed rapid identification and inclusion of these key areas, as well as more equal distribution of the workload of malaria control field staff.

Conclusion

The procedure developed enables complete coverage of targeted areas with larval control through comprehensive spatial coverage with community-derived sketch maps. The procedure is practical, affordable, and requires minimal technical skills. This approach can be readily integrated into malaria vector control programmes, scaled up to towns and cities all over Tanzania and adapted to urban settings elsewhere in Africa.

5.2 Background

Urban malaria and its historical control in Dar es Salaam

Malaria is responsible for more than one million deaths world-wide each year, mainly in sub-Saharan Africa (Hay et al. 2005, Snow et al. 2005, WHO & UNICEF 2005). In areas prone to malaria, urbanization has major implications for the transmission and epidemiology of malaria (Lines et al. 1994, Warren et al. 1999). Although malaria vector density is typically much lower in urban areas compared to periurban and particularly rural areas (Robert et al. 2003), malaria transmission in urban and periurban settings remains a significant problem (Granja et al. 1998, Hay et al. 2005, Imbert et al. 1997, Snow et al. 2005, Trape et al. 1993). In Dar es Salaam, over a million malaria cases are reported by the health facilities every year (Mtasiwa et al. 2003), though malaria is clearly grossly overreported (Makani et al. 2003, Reyburn et al. 2007, Wang et al. 2006) and a considerable part of the infections might result from travel to rural areas (Wang et al. 2006). Ninety percent of all malaria cases in Dar es Salaam are caused by *Plasmodium falciparum*, and the main vectors in this major urban centre are *Anopheles gambiae sensu strictu* Giles, *Anopheles arabiensis* Patton, *Anopheles funestus* Giles and *Anopheles merus* Dönitz (Castro et al. 2004).

Dar es Salaam has a long history in malaria control, starting more than 100 years ago in the German colonial era (Clyde 1961, Mukabana et al. 2006). A variety of techniques has been used to control malaria in the city for many decades, with considerable success (Castro et al. 2004). In 1972, economic and political reasons led to chemotherapy being the only anti-malaria intervention left in place. As a result, the density of *Anopheles* mosquitoes started to increase again (Kilama & Kihamia 1991). Starting in 1988, the City of Dar es Salaam collaborated with the Japan International Cooperation Agency (JICA), focussing on vector control, promoting people's perceptions of malaria and involving communities in environmental management activities (Castro et al. 2004, Mukabana et al. 2006). Despite some successes such as the rehabilitation of drainage infrastructure, this programme did not achieve sustainability and ended in 1996. Main reasons for this are considered to be insufficiently developed local ownership and capacity (Mukabana et al. 2006).

The Dar es Salaam Urban Malaria Control Programme

The aim of the current Dar es Salaam Urban Malaria Control Programme (UMCP) is to control aquatic-stage mosquitoes using community-based resource persons (CORPs), and to evaluate the effectiveness of this intervention (for definitions and abbreviations please refer to Table 5.1). The goals of the UMCP are part of the National Malaria Control Programme, which comprises vector control, improved malaria case management, malaria prevention in pregnancy, epidemic management and strengthening of systems for delivering and managing these interventions (Tanzanian Ministry of Health & World Health Organization 2004). The UMCP has developed out of a local initiative: in 2002, the Ilala Municipal Council independently planned, funded and implemented a community-based mosquito surveillance programme. Two years later, this programme was scaled up to 15 of the 73 wards of Dar es Salaam, covering an area of 56 km² (
Figure 5.1), with support from national and international academic partners (Mukabana et al. 2006). All UMCP activities are coordinated by the City Medical Office of Health, and are fully integrated into the decentralized administrative system in Dar es Salaam (Figure 5.2). The UMCP in its current form was launched in March 2004 and operates on all five administrative levels of the city: the city council, 3 municipalities, 15 wards, 67 neighbourhoods referred to as *mitaa* in Kiswahili (singular *mtaa*, meaning literally street) and more than 3000 ten-cell-units (Table 5.1 & Figure 5.2). The main tasks on the four upper levels are project management and supervision, whereas the actual monitoring, mosquito larval surveillance and control is organized and implemented at the level of the smallest administrative units, the so-called ten-cell-units (TCUs). A TCU typically comprises about ten houses, in some cases even more than one hundred. Each TCU is headed by an elected chairperson (Mtasiwa et al. 2004, Mukabana et al. 2006). The core activities of the UMCP are implemented by CORPs to whom specific responsibilities and target areas are allocated (Table 5.1 & Figure 5.2). On a weekly basis, they monitor and document the larval habitats of mosquitoes in every ten-cell-unit, receiving minimal remuneration (Mukabana et al. 2006, Vanek et al. 2006). The exact number of ten-cell-units that each CORP is responsible for varies depending on their sizes and characteristics. Starting in March 2006, additional CORPs have been recruited and trained to apply biological larvicide (*Bacillus thuringiensis* var. *israelensis*) to all potential larval habitats of malaria vectors. Thus, there are two groups of CORPs: the larval surveillance CORPs and the larviciding CORPs. This article only refers to those CORPs who are responsible for larval surveillance and monitoring.

Table 5.1: Definitions and abbreviations

CORP:	Community-Owned Resource Person. The responsibility for routine mosquito surveillance in Dar es Salaam is delegated to individual community members (CORPs) who are appointed and managed through neighbourhood health committees (Mukabana et al. 2006).
GIS:	Geographical Information System. A GIS is a computer system for capturing, storing, analyzing and managing data and associated attributes which are spatially referenced to the earth (Lillesand et al. 2004, McCloy 2006).
GPS:	Global Positioning System (Lillesand et al. 2004, McCloy 2006).
Municipality:	The Dar es Salaam City Region is subdivided into three municipalities, namely Ilala, Temeke and Kinondoni.
Open Space:	Public or private unbuilt land, for example hazardous lands declared not suitable for construction, road reserves, available land for community use, as well as residential, industrial or institutional plots under-utilised or awaiting development. Open spaces are often used for agricultural activities.
Plot:	All TCUs within the wards covered by the UMCP are subdivided into plots. A plot is defined here as a specific physical area with an identifiable owner, occupant or user and with clearly defined boundaries within one specific TCU. The plot boundaries are defined by UMCP staff. Therefore, the plots do not always correspond with actual cadastral information such as land ownership (Urban Malaria Control Project 2004).
Neighbourhood:	The 73 wards of the Dar es Salaam City Region are administratively subdivided into 368 neighbourhoods. The 15 wards covered by UMCP comprise 67 neighbourhoods. The local Kiswahili term for neighbourhood is *mtaa* (plural *mitaa*) which literally means “street”.
TCU:	Ten-Cell-Unit. The 368 neighbourhoods (*mitaa*) of the Dar es Salaam City Region are subdivided into several thousand ten-cell-units (TCUs). They typically comprise about ten houses, in some cases even more than one hundred, and are headed by an elected chairperson. Some non-residential areas were not included in any TCU by the time the UMCP started. In the progress, such areas were assigned to be new TCUs, or were attached to existing TCUs in all neighbourhoods within the UMCP.
UMCP:	Urban Malaria Control Programme of the Dar es Salaam City Medical Office of Health, in co-operation with national and international research and funding organizations.
Ward:	The three municipalities of the Dar es Salaam City Region are subdivided into 73 wards. Currently, 15 of these wards are covered by the UMCP.

Targeting of the most productive habitats could improve the cost-effectiveness of mosquito larval control in Africa (Gu & Novak 2005). Remotely sensed imagery, GIS and GPS can support the identification and recording of such habitats on village or city level (Castro et al. 2004, Diuk-Wasser et al. 2004, Keating et al. 2004, Mushinzimana et al. 2006, Sattler et al. 2005, Sithiprasasna et al. 2005). However, the operational challenges of a large-scale programme and the lack of scientific evidence of its feasibility and effectiveness suggest the need for exhaustive coverage and very simple implementation protocols that can be implemented by community-level staff with minimal education. This is essential if larval control is to achieve substantial reductions of malaria transmission and disease burden

(Killeen et al. 2006b), considering the highly dynamic nature of mosquito larval habitats in urban areas that are often too small to be identifiable on aerial pictures (Killeen et al. 2006b, Sattler et al. 2005). In order to provide the necessary basis for this goal, the CORPs record and monitor all potential mosquito habitats. However, an evaluation of the CORPs work in the first months of the programme from March to June 2004 revealed the need for new procedures such as the ones presented in this paper, in order to tighten up the standards of community-based larval control. During the previous evaluation, the CORPs detected less than 50% of all breeding sites (Vanek et al. 2006), which is unlikely to achieve satisfactory impact on malaria transmission if this is considered an upper limit for coverage with insecticide (Killeen et al. 2006b).

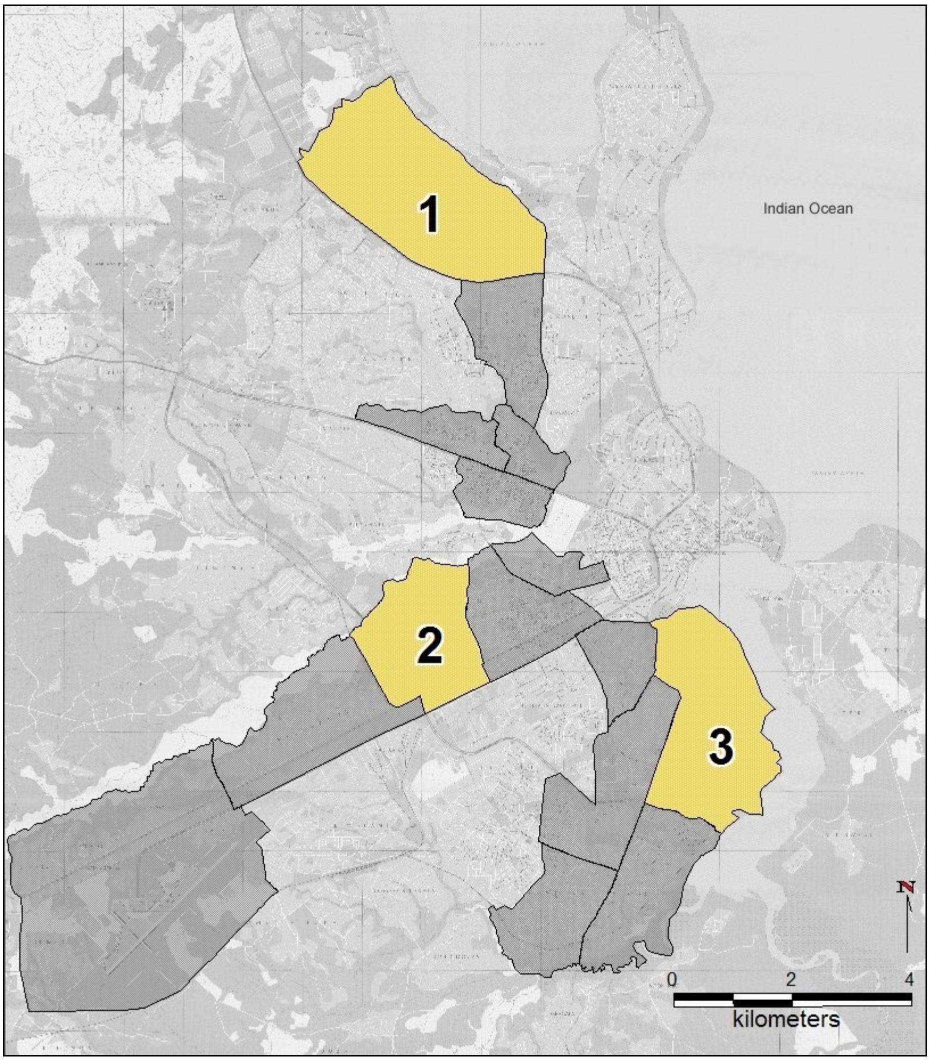

Figure 5.1: Project wards of the Dar es Salaam Urban Malaria Control Programme

Dar es Salaam City Map. The dark grey and yellow shaded areas show the 15 wards in which the UMCP is operating at present. The yellow areas mark the first three wards that were systematically mapped using the methodology described here. 1 – Mikocheni, 2 – Buguruni, 3 – Kurasini. Source of background map: Dar es Salaam City Map and Guide, published in 1995 by Surveys and Mapping Division, Tanzania.

Administrative level:	UMCP staff for larval surveillance:
Country	
Region (Dar es Salaam City Region)	City Malaria Control Coordinator, City Malaria Surveillance Officer, City Mapping Officer, Mapping Technician
Municipality/District	Municipal Malaria Control Coordinator, Municipal Malaria Control Inspector
Ward	Ward Malaria Vector Control Supervisor
Neighbourhood/Village	Community-Owned Resource Person (CORP)
Ten-Cell-Unit/Hamlet	

Figure 5.2: Administrative levels in Tanzania and UMCP larval surveillance

For purposes of clarity, the above overview only encompasses staff working full or part time for and paid by the UMCP. In fact, there are more institutions involved in programme implementation on each administrative level (Ifakara Health Research and Development Centre 2005), such as the city medical officer, the municipal health board, the ward executive officer and the neighbourhood health committee.

This article is part of a series of papers that present results from different elements of the UMCP programme (Castro et al. 2004, Mukabana et al. 2006, Sattler et al. 2005, Vanek et al. 2006). Future articles will show that larval control does work and is effective in reducing malaria burden in Dar es Salaam (unpublished data), and specify the surveillance methodology. This paper describes a community-based participatory mapping procedure that can be used to overcome the challenges described above, and allows the integration of the valuable knowledge of community members. The approach aims to enable complete coverage of targeted communities with larval control by optimising the quality and spatial coverage of community-derived sketch maps. The overall goal of developing this procedure is to improve programme management systems in a way that makes routine larval surveillance and control truly effective. The approach described is easily replicable, adaptable and transferable to any other city in Tanzania or Africa, provided the necessary resources and policy support are available. It particularly takes into account the resource situation and limited availability of maps and remote sensing data in such settings, which cannot be compared to western countries.

5.3 Methods

Study area

This study was conducted in urban Dar es Salaam, the largest city and *de facto* capital of Tanzania with almost 2.7 million inhabitants in 2005 (UN 2006). Situated on the shores of the Indian Ocean, with large parts of the city located only a few meters above sea level, Dar es Salaam has a hot and humid tropical climate with two rainy seasons and is characterized as an area with endemic and perennial malaria, with transmission occurring during the entire year (MARA/ARMA 2002). The administrative city region covers an area of almost 1,400 km^2 (Castro et al. 2004), of which 56 km^2 are covered by the fifteen wards included in the UMCP at present (

Figure 5.1). Although the UMCP area only makes up for 4% of the overall city region, it covers some of the most densely populated parts of the city. It is inhabited by more than 610,000 people, and therefore almost a quarter of the total population (National Bureau of Statistics 2003). Most of this area is built-up, but nevertheless provides excellent breeding sites for mosquitoes (Castro et al. 2004, Sattler et al. 2005), especially where the groundwater table is high. In Dar es Salaam, almost all kinds of water accumulations can be breeding sites for *Anopheles sp*. larvae (Sattler et al. 2005). The participatory mapping procedure described here was developed in three of the fifteen UMCP wards. These three wards had been selected as study area because the UMCP had chosen them as the first wards to implement community-based larval control starting from 2006.

Resources needed

The resources and materials necessary for the creation of sketch maps and their verification are listed in Table 5.2, together with an indication of their respective costs.

Preliminary sketch mapping

The framework within which the daily work of the CORPs is conducted is a set of sketch maps of their areas of responsibility (Figure 5.3A). Their creation is the first activity in the mapping sequence described here. The first round of sketch mapping in Dar es Salaam was initiated in 2004. The CORPs drew preliminary sketch maps of all existing TCUs located within the programme area. For this endeavour, they were supported and trained by UMCP staff, and provided with printed standard operating procedures as reference material (Urban Malaria Control Project 2004)[18]. The original sketch maps and corresponding description forms were filed at the respective ward offices, and a copy brought to the city council for central information management.

Table 5.2: Costs of participatory mapping

Activity / Item	Costs in TSh (2005)	Costs in USD	Costs per km^2 in USD	Costs per TCU in USD
Technician (BSc in Geography or equivalent; skilled in working with communities, GIS and aerial imagery)	2,450,000	2,156	129	3.7
Field assistant (trained by technician)	1,050,000	924	55	1.6
CORPs (responsible for and familiar with the area to be mapped, and respected by the community)	780,000	686	41	1.2
Training for CORPs in sketch mapping (implemented by UMCP management team and technician)	200,000	176	10	0.3
Aerial photographs (printed; resolution of 1m or better and colour images recommended)	5,000,000	4,400	262	7.5
Lamination (for protection of printed aerial photographs)	50,000	44	3	0.1
Stationary & copy costs (mapping templates for TCU sketch maps, description forms for each plot, pens)	300,000	264	16	0.4
Computer with GIS software (for example MapInfo Professional 6.0, ArcView 3.2 or more recent versions)	2,500,000	2,200	131	3.7
Colour printer & cartridges	1,200,000	1,056	63	1.8
Motorbike (optional) & fuel	2,300,000	2,024	121	3.4
Total	**15,830,000**	**13,930**	**831**	**24**

The costs of the participatory mapping for a total of three wards (16.8 km^2) with a total of 589 TCUs are calculated on the following basis: Two CORPs per day with a daily remuneration of TSh 3,000 per person, with five working days per week over a period of six months. Exchange rate: TSh 1,000 = USD 0.88 (source: www.oanda.com, September 1, 2005). The amount for item “aerial photographs” may vary due to availability; adequate imagery might be freely available, e.g. from Google Earth™.

The purpose of the sketch maps is to enable the CORPs to assign a unique number to any larval habitat found within a plot and enable supervisory staff to identify it unambiguously when inspecting the work of that CORP. Features included in the sketch maps are roads,

[18] The published version of this paper contains a link to an additional file, which is not directly relevant in the context of the thesis *(Guidelines for 10-cell unit mapping to be carried out by the Community-Owned Resource Persons and the wards malaria vector control supervisors)*. These guidelines describe the procedure for sketch mapping in detail, and have been distributed by the UMCP management to the CORPs and their supervising staff. They can be downloaded from the journal’s website: http://www.ij-healthgeographics.com/content/supplementary/1476-072x-6-37-s1.pdf

pathways, drains or other landmarks, boundaries of the TCUs, and a subdivision of the whole TCU area into individually numbered plots based on regular use or ownership (Urban Malaria Control Project 2004). Attached to every sketch map is a description form that contains details about each plot such as house number, name of the household head or characteristics of the area (Urban Malaria Control Project 2004) (Table 5.1). There is one sketch map for each TCU.

The sketch maps do not necessarily look like the area itself from the air (Figure 5.3B), but nevertheless provide good guidance for the CORPs in the field. One obvious advantage of the system is that it corresponds to the existing administrative boundaries. This makes it easier for the CORPs to orient themselves in the field, as most community members are aware of the number of the TCU their household is located in, and thus can be asked if in doubt.

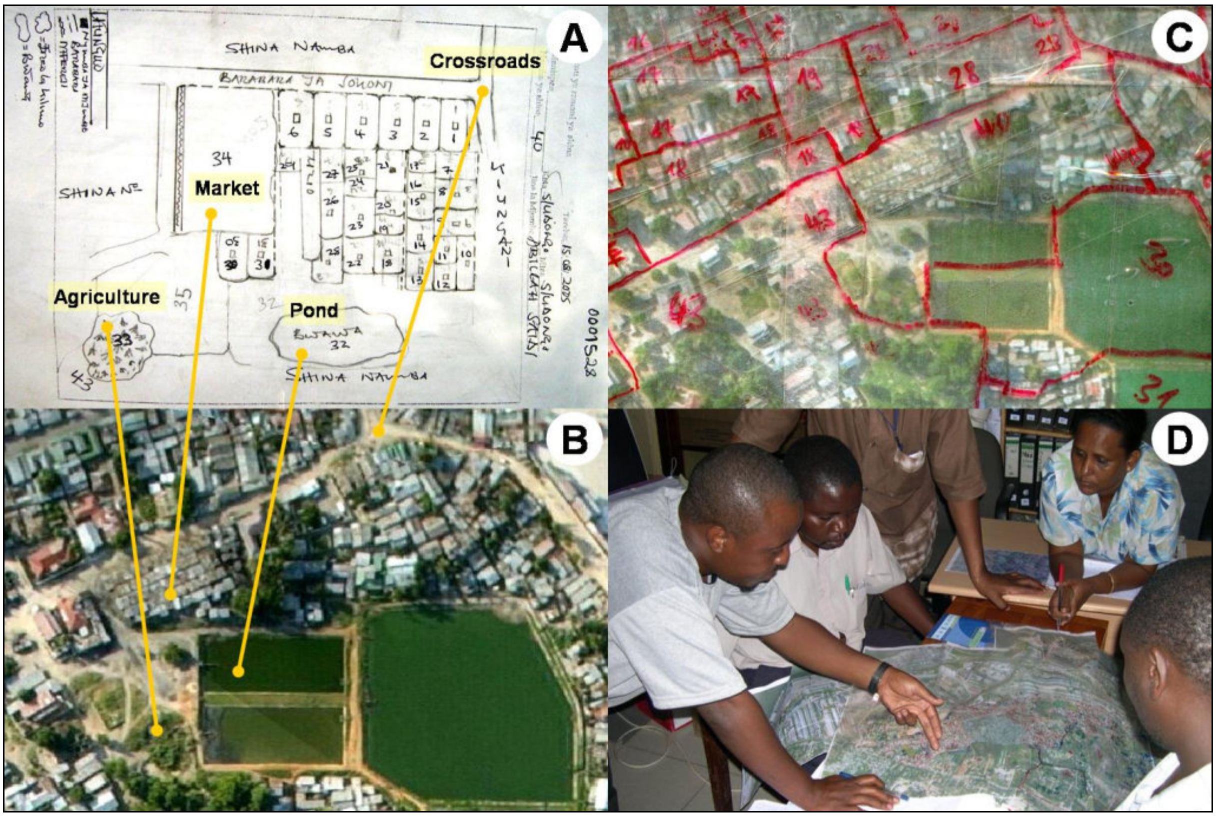

Figure 5.3: Example of a sketch map, aerial picture and technical map

A. Sketch map of TCU 40 in Kurasini ward, Shimo la Udongo neighbourhood, as drawn by the responsible CORP. Features comprise plots with continuous numbering, streets, drains, agricultural areas and ponds. B. The same area on the aerial picture. The yellow lines are connecting identical features on the sketch maps and the aerial picture. C. The same area on the laminated aerial photograph used for the technical mapping in the field. The features to be mapped were marked with non-permanent marker pens. Red: TCU boundaries and TCU numbers. D. Project management team discussing over the technical map of a whole ward, and deciding on necessary follow-up actions.

Technical mapping with aerial photographs

In the next step, which will be referred to as "technical mapping" as opposed to "sketch mapping", the preliminary sketch maps were verified, corrected and formalized in the field by a technical team in collaboration with the CORPs. By using aerial photographs, all boundaries of TCUs, neighbourhoods and wards were formally mapped. The basis for the technical mapping was a digital aerial picture of Dar es Salaam in colour, taken in 2002 (ground resolution 0.5m, produced by Geospace International, Pretoria, South Africa). This picture covers the whole urban area of Dar es Salaam. The relevant segments of the picture were colour printed as a mosaic of A4 pages at a scale of 1:3,000. The prints were laminated in order to protect them during intensive use in the field, and to allow drawing on the transparent surface with non-permanent marker pens that can easily be erased again for corrections (Figure 5.3C). Finished parts of the map were covered with transparent sticky tape for protection of the drawings.

After meeting all stakeholders, including the CORPs, at the local government office, the area to be technically mapped on the respective day was agreed on. The technical team showed a sample map so that everybody could understand how the technical map should appear in the end. This particularly helped avoiding the potential misunderstanding on the side of the CORPs that the technical team came to evaluate their work with the possibility of disciplinary action. Such perceptions proved very counterproductive because they greatly limited open interaction between the CORPs and the technical mapping team. The technical team and the responsible CORPs then went to the nearest TCU he or she was working in, together with the respective preliminary sketch maps (Figure 5.3A), description forms, and laminated aerial photograph (Figure 5.3C & D). The CORP was asked to take the team to the boundary of the TCU. After reaching it, the position was marked on the photograph as the starting point (Figure 5.4B). The team then walked along the boundary with the neighbouring TCU. The boundary was continuously marked on the photograph (Figure 5.4C), and regular stops were made to verify accuracy. While walking, the CORPs were asked repeatedly which TCU was on the left side, and which one on the right. As soon as another border with a different adjoining TCU was reached, the team marked the three-way intersection of the TCU being mapped and the two adjacent TCUs (Figure 5.4C & D). This procedure was continued until the starting point was reached again (Figure 5.4D). If it was not possible to walk along the boundary due to construction or other obstacles, it was ensured that what was marked in the technical map represented the actual agreed border. With the same procedure, all existing

TCUs within a ward were mapped. By doing so, previously unsurveyed areas were identified and included into the sketch maps.

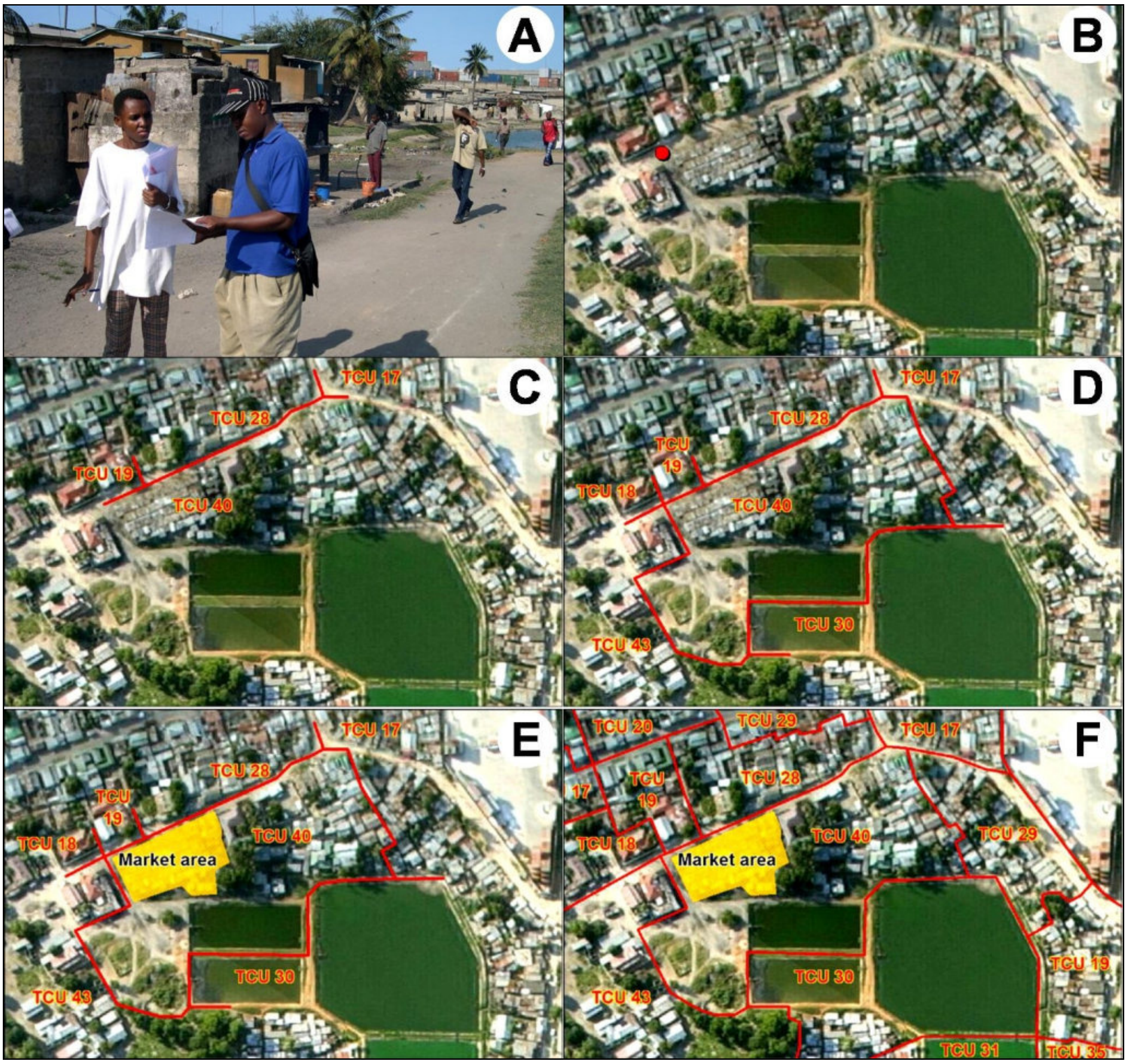

Figure 5.4: Technical mapping of a TCU

The underlying scene is taken from the aerial picture and shows TCU 40 and its surroundings in Kurasini ward, Shimo la Udongo neighbourhood. The large green structures in the lower half of the picture are sewage ponds. A. Mapping technician and CORP walking along the boundary of the TCU. The sewage ponds are visible in the background. B. The starting point is marked on the map. C. Marking the boundary of TCU 40 in red colour while walking along the boundary. The neighbouring TCU numbers and three-way-intersections are marked at the same time. D. Reaching the starting point again. E. The technical mapping of TCU 40 is finished. The market area has been identified as unsurveyed and is marked in yellow colour. F. Final technical map including the neighbouring TCUs.

Identification of missing areas and correction of sketch maps

Some of the identified unsurveyed areas were relatively small and easy to integrate into the sketch maps, whereas others turned out to be very large and required a more complex follow-up action by inclusion into newly created TCUs. Problems related to small areas could be solved directly on the spot. After the technical mapping of each single TCU, the team thoroughly checked for unsurveyed areas within that TCU. The sketch map had to cover exactly the same area as marked on the aerial photograph, and all areas within the TCU had to be assigned to a specific plot so that all plots could subsequently be surveyed by CORPs for mosquito larval habitats on a regular and routine basis. Omissions of certain areas from the sketch maps were immediately corrected by assigning a new plot number or by adding an area to an existing plot on the sketch map. Any unsurveyed areas included by the technical team were marked for documentation, and included in the sketch maps and description forms immediately. This means that the TCUs defined by the UMCP are not always identical to administrative TCUs in terms of their boundaries.

In the case of access-restricted, relatively large unsurveyed areas that did not belong to any TCU, new TCUs were created by the CORPs together with their supervising staff. The boundary lines of the new TCUs were defined, and new TCU numbers assigned. Permission for regular access to all properties located within the new TCUs was sought and obtained by the programme management on municipal level. Finally, the new sketch maps were formalized and corrected in exactly the same way as described above.

Digitization of technical maps and provision for operational teams

As the last working step, the technical maps based on the aerial imagery were digitized. Provided that the aerial imagery used is available in digital format, only a computer with GIS software is needed. Digitization and data analysis was done with the GIS software package MapInfo Professional® 7.0 [MapInfo Corporation, One Global View, Troy, New York 12180]. The aerial imagery was georeferenced, which means that geographical coordinates (UTM, longitude/latitude) were available for each point of the image. This is the case with most commercial remotely sensed imagery, but can also be done by identifying a few reference points of which the coordinates are known (possible sources are topographical maps or a standard GPS receiver) (Lillesand et al. 2004, McCloy 2006). The digitizing itself was done “on screen” with a computer, by creating separate layers for TCUs, neighbourhoods, wards, unsurveyed areas and text labels. The latter comprise useful features such as landmarks and street names, and consist of points with attribute data. All other layers consist of polygons with attribute data such as TCU numbers, names of wards, neighbourhoods and names of responsible CORPs, characteristics of each area and automatically calculated sizes of each polygon.

After digitization, each ward and the mapped features were printed as colour maps (Figure 5.5). One colour map per ward was kept on file at the city office together with copies of all corrected sketch maps and description forms. A large-scale colour print of each ward map was laminated and returned to the respective local government offices, where the originals of the sketch maps and description forms are stored while not in use by the CORPs. During operations, the colour maps are mostly used by supervisory staff for evaluation of the CORPs work and assurance of complete larval control coverage.

5.4 Ethical considerations

All work during this study was on geographical material and did not involve human subjects. Research clearance was obtained from the Medical Research Coordination Committee of the National Institute of Medical Research in Tanzania (NIMR/HQ/R.8a/Vol. IX/279) and the Tanzanian Commission of Science and Technology (No. 2004-69-MFS-2004-24 and No. 2005-123-NA-2004-163). This manuscript has been published with kind permission of the Director of the National Institute for Medical Research of the United Republic of Tanzania. In order to achieve community consent and before starting any field work, the stakeholders and community leaders at the respective local government units were contacted. The goals of the activity were explained, and the mapping team was introduced. All responsible CORPs and the programme management staff in charge for an area to be mapped were present in such meetings.

5.5 Results

Three complete wards covering a total area of 16.8 km², consisting of 12 neighbourhoods and 589 TCUs, were mapped during several phases with interruptions between March 2004 and January 2006 (Figure 5.5). The mapping comprised the community-based creation of sketch

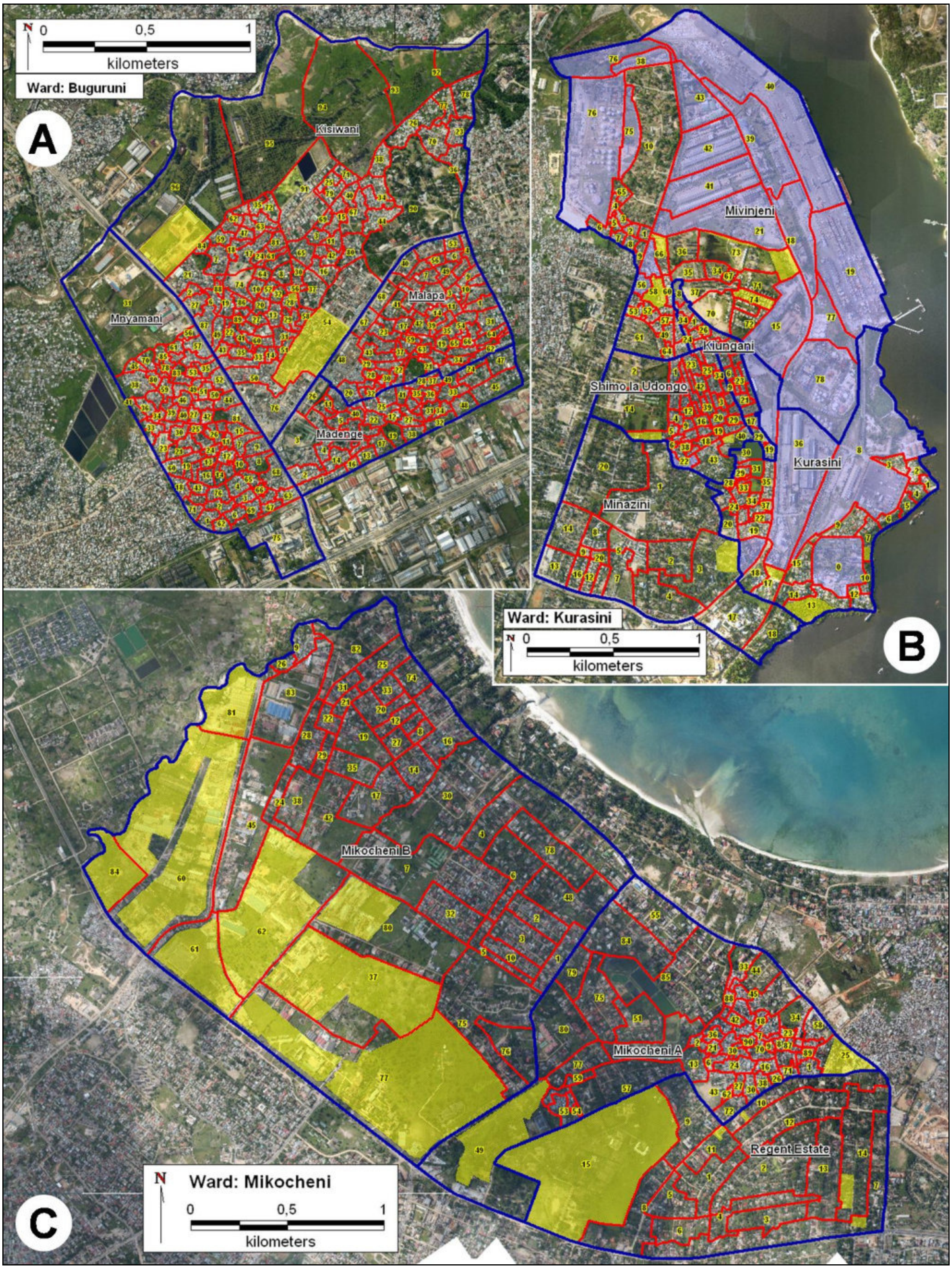

Figure 5.5: Final technical maps of the three study wards

A. Buguruni ward. B. Kurasini ward. C. Mikocheni ward. Red lines: TCU boundaries, numbers: TCU numbers, blue lines: neighbourhood boundaries, yellow areas: initially unsurveyed by CORPs, blue areas: initially unsurveyed by CORPs and now included in newly created TCUs.

maps and their verification by a technical team using laminated aerial photographs. The mapped area is equivalent to 30% of the total project area and home to 128,000 people (National Bureau of Statistics 2003). The total time needed for the actual work was six months. Overall, it was found that before the technical mapping, only 14.0 km^2 (83.3%) of the study area had been included in TCUs, and only 11.5 km^2 (68.4%) of the study area had been surveyed for mosquito larval habitats by CORPs (Figure 5.6A). This means that by that time, 2.8 km^2 (16.7%) of the survey area were not covered by existing TCUs or any sketch maps. Even where TCUs existed and sketch maps for those were available, 2.5 km^2 (14.9%) of those TCUs were not represented in the sketch maps or surveyed by CORPs. Immediately after their identification, all these shortcomings were solved by either adding areas to existing sketch maps (Figure 5.5, areas marked in yellow), or by creating new TCUs and corresponding sketch maps where necessary (Figure 5.5, areas marked in blue). For the purposes of facilitating surveillance and management activities, additional TCUs were created as a result of division of larger TCUs. Overall, the total number of TCUs grew by 27 (4.8%) compared to the first round of sketch mapping.

In the course of the technical mapping, shortcomings of the TCU-based surveillance system were identified and eliminated. All of them initially contributed to gaps in terms of areas that were not surveyed for mosquito larval habitats by any CORP. Non-residential areas such as industrial areas, commercial areas and open spaces (Table 5.1) are not usually part of any TCU or residential lists. Therefore, they often were not included in preliminary sketch maps. Furthermore, some CORPs at first did not understand that such areas are important for their work, and tended to focus on residential areas. Other initially unsurveyed areas resulted from misinterpretation of actual TCU boundaries by the CORPs. Such misinterpretations often happened where the boundaries between TCUs did not coincide with intuitive landmarks such as roads, but were located in less structured areas such as river valleys without residential areas. In such cases, all responsible CORPs including those from adjacent TCUs, their supervisors and the technical team revisited the area. The borders between their respective areas could then be assessed properly with full participation by all responsible for and familiar with the area.

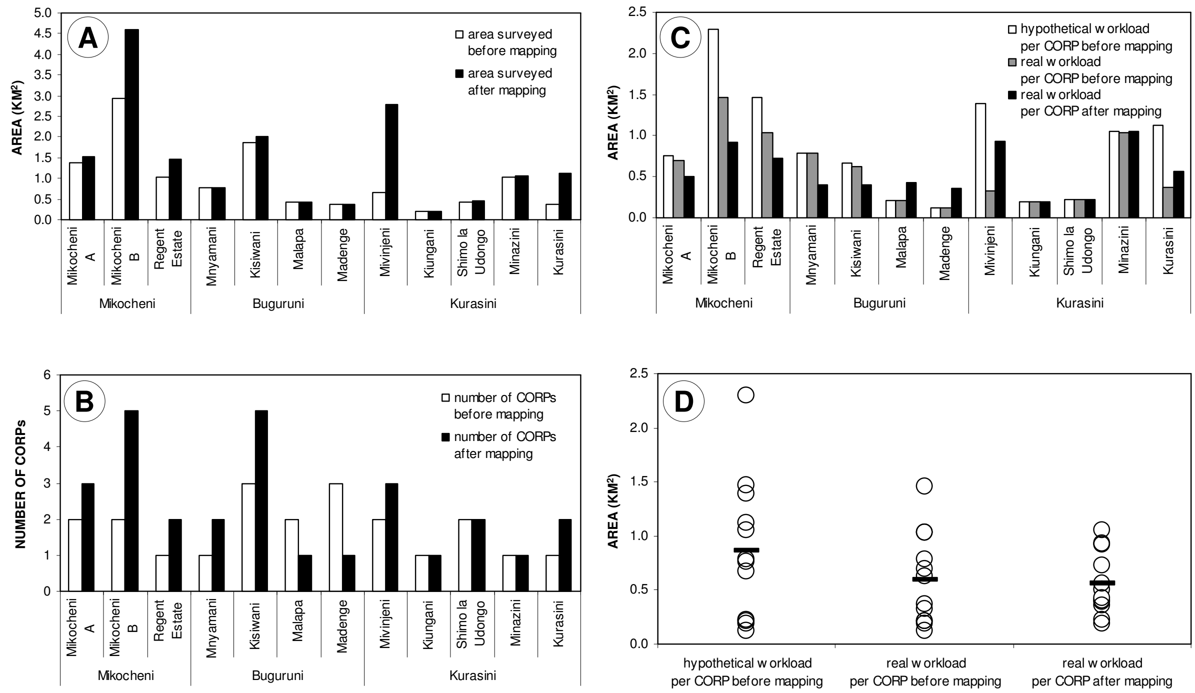

Figure 5.6: Impact of technical mapping

Situation in each of the 12 neighbourhoods of the study area, directly before and three months after the preliminary sketch maps were formalized and corrected by using the technical mapping approach with aerial photographs. A. Total area in km^2 surveyed by CORPs (*) before and after technical mapping. The latter is equal to 100% of the surface area of all 12 neighbourhoods. B. Number of CORPs before and after technical mapping. C and D. Average weekly workload per CORP in km^2 (**) before and after technical mapping. “Hypothetical workload” assumes that the sketch maps had been correct and leaving no gaps within each neighbourhood from the beginning, and that the CORPs had surveyed all these areas even before the sketch maps were verified. “Real workload” only takes into account the area actually surveyed by CORPs. The circles represent the 12 neighbourhoods, and the horizontal bars represent the arithmetical means.

(*) area which is routinely and weekly monitored by CORPs, and for which sketch maps plus description forms are available
(**) weekly workload is calculated as the total area of a neighbourhood divided by the number of CORPs working in the respective neighbourhood

Mikocheni ward

Mikocheni (Figure 5.5C) with a total area of 7.6 km^2 is subdivided into three neighbourhoods (Mikocheni A, Mikocheni B and Regent Estate). The northern parts of Mikocheni A and B as well as the whole of Regent Estate are low and medium density residential areas, with residents of relatively high socio-economic status. Plots in this area are typically well defined by walls or fences. The same is true for the industrial and commercial areas in the south of Mikocheni B. For the CORPs this means that they have to ask watchmen or owners for permission every time they want to enter such plots, which was the main reason for not surveying such properties for larval habitats initially. In Regent Estate, there were some residential plots where the CORPs were not allowed to enter, or were not willing to do so because of watchdogs or the intimidating reputation of the owner. All these cases were effectively resolved by informing the municipal malaria coordinator, who ensured access by writing formal letters and arranging meetings with the concerned companies and individuals. A special arrangement was necessary for TCU 84 at the western corner of Mikocheni B, which is owned by the armed forces. In this case, the solution agreed between army representatives and the municipal malaria coordinator was to recruit an extra CORP from among the army personnel. Notably, no problems occurred in the cluster of unplanned residential TCUs in the east of Mikocheni A. In this area, characterized by high housing density and low socio-economic status, only few plots are fenced, and access was granted in all cases. The initially unsurveyed area in the eastern corner of Mikocheni A belongs to a shopping mall. The planned and unplanned areas can be easily distinguished in the colour maps by the different courses of their TCU boundaries. In planned areas, the lines are relatively straight and smooth, but they appear rather irregular and uneven in the unplanned part in the east of Mikocheni A. In addition, TCUs in planned settings are generally a lot larger compared to those in unplanned ones, due to the size of the houses and corresponding plots.

Buguruni ward

Buguruni ward (Figure 5.5A) with a total area of 3.6 km^2 consists of four neighbourhoods (Mnyamani, Kisiwani, Malapa and Madenge). Although it is a lot smaller than Mikocheni, it consists of more than twice as many TCUs. This reflects the fact that the residential parts of Buguruni are largely unplanned settlements with high housing density and a relatively low socio-economic background, characterized by small TCU sizes. The few relatively large TCUs are industrial areas, belong to the police and churches, or are used for agricultural purposes such as the northern part of Kisiwani which is located in a river valley (TCU 92-96). In order to ease the work for the CORPs in this huge agricultural area, the local field and supervisory staff came up with a special way for defining TCU and plot boundaries. These initiatives were initiated by the technical mapping, during which confusions about TCU and plot boundaries on behalf of the CORPs became obvious. The collaboration with staff on all administrative levels stimulated creative, participatory and solution-oriented action. Comprehensive larval surveillance was achieved by using coconut trees as boundary indicators, and by marking their stems with the respective numbers (Figure 5.7). The few unsurveyed areas that had to be included were all due to the initial restriction of the owners to let the CORPs enter their plots.

Figure 5.7: Painted coconut tree

For better orientation, the responsible field & supervisory staff painted plot and TCU numbers on coconut trees in a large uninhabited agricultural open space of Buguruni ward (TCU 92-96).

Kurasini ward

Kurasini ward (Figure 5.5B) comprises five neighbourhoods (Mivinjeni, Kiungani, Shimo la Udongo, Minazini and Kurasini). It is characterized by large commercial harbour areas and petrol industries located in the northern and eastern parts. All of these areas were initially not surveyed and had to be included into the surveillance system. Most of them were not part of existing TCUs. Therefore, 22 new TCUs and corresponding sketch maps were created by the responsible field and supervisory team (blue areas in Figure 5.5B). Access to those areas was established through formal letters to and discussions with company representatives. The south-western half of Kurasini ward is residential area. Similar to the situation in Mikocheni, there are planned low and medium density as well as unplanned high density settlements, which can be distinguished by their differing TCU sizes and boundary characteristics. Within the residential areas, several initially unsurveyed areas were included into the survey system. Three areas were found unsurveyed due to their uninhabited status, namely a bush area, a mangrove swamp, and an open space. A commercial area was included in Minazini. The remaining initially unsurveyed areas had been difficult to access, such as fenced industrial plots. However, these areas were readily assimilated through intervention of senior municipal staff, as described for Mikocheni.

The technical mapping revealed that the sizes of TCUs vary tremendously. The smallest TCU (0.0013 km^2) was found in Buguruni Malapa. Before the sketch maps were corrected, the largest TCU with almost 0.9 km^2 was located in Buguruni Kisiwani. After subdividing it into the smaller TCUs 92-96, the maximum TCU size today is 0.6 km^2 (TCU 77 in Mikocheni B). Apparently, these variations had not been adequately considered in the initial allocation of work areas to CORPs. Some CORPs had been assigned relatively small areas, whereas others were responsible for much larger areas (Figure 5.6A & B). The technical mapping led to the redistribution and reallocation of the work areas per CORP, and the recruitment and training of additional CORPs where necessary (Figure 5.6B & C). The average weekly workload per CORP is defined here as the surface area of a neighbourhood divided by the number of CORPs assigned to this neighbourhood. Hypothetically, i.e. if the sketch maps had been correct and leaving no gaps within each ward from the beginning, and if the CORPs had really surveyed all areas before the sketch maps were verified, this would have resulted in an average weekly workload of almost 0.9 km^2 per CORP (Figure 5.6C & D). In reality, only 0.6 km^2 per CORP and week had been surveyed on average, which lead to large unsurveyed gaps equivalent to a 31.6% shortfall in spatial coverage. After the correction of the sketch maps, each CORP is now responsible for an average of slightly less than 0.6 km^2 per week. Considering the average weekly workload of all CORPs, the largest area to be surveyed by a CORP has decreased from 2.3 km^2 before the technical mapping to 1.1 km^2 afterwards. At the same time, no CORP was responsible for surveying less than 0.2 km^2 after the technical mapping, compared to 0.1 km^2 before (Figure 5.6C & D). Thus, the workload per CORP has been distributed more equitably, which is likely to impact the quality of work.

5.6 Discussion

The community-based participatory mapping represents a useful tool for urban mosquito larval control. After its completion, corrected sketch maps, description forms and formalized colour maps based on an aerial photograph were available for the complete study area. On this basis, 100% spatial coverage of mosquito larval habitat surveillance by CORPs was achieved, which would have been impossible with either the sketch maps or the formalized colour maps alone.

From the point of view of programme field workers including CORPs, the sketch maps and associated detailed plot descriptions are indispensable guidance tools. The sketch map system accommodates the different cognitive abilities of the CORPs, as the map style can be adapted according to their personal preferences in order to achieve optimal orientation. However, only few CORPs were comfortable to use an aerial photograph as a basis for their work, which rules out the option of replacing all sketch maps with formalized maps. Nevertheless, CORPs who wish to use formalized maps as an addition to their sketch maps can be provided with laminated printouts. When a CORP has to be replaced, the successor takes over the existing sketch maps but is free to adjust or redraw them if desired.

From a programme management perspective, the sketch maps are an ideal method to assign a unique number to each plot, whereas the technical mapping approach with aerial imagery proved to be essential for the verification and correction of the sketch maps. Moreover, the georeferenced colour maps that show the demarcations and locations of TCUs enable management staff to assess and analyze the data collected by the CORPs, and to conduct targeted spot checks.

The use of GIS software in the mapping approach proved to be extremely helpful for programme management and supervision of field activities, although only basic functions were utilized. Similar positive findings have also been made in other malaria control programmes in South Africa and Mozambique (Booman et al. 2000, Booman et al. 2003, Martin et al. 2002), and public health in Africa generally (Tanser & Le Sueur 2002). The approach does not require any electronic devices such as GPS receivers in the field. In addition, if digital aerial imagery is available, costly equipment like digitizing tablets or large format scanners are not needed. The entire GIS database as well as all subsequent updates thereof has been made available to the central GIS unit of the Dar es Salaam City Council. It can be used as a basis for any Council activity such as health interventions, waste management programs, and urban planning, to name a few.

The mapping approach adheres to the existing administrative boundary system in Tanzania, mainly referring to the ten-cell-units. In a dynamic environment such as the rapidly growing city of Dar es Salaam, this allows optimal orientation for community-based programme staff in the field, without having to create entirely new sets of artificial boundaries. Whenever there are changes, sketch maps can easily be updated during their weekly use by the CORPs. The technical team only needs to be informed in case TCU boundaries have been modified. It is argued that this approach has practical programmatic advantages over imposed raster grid systems (Eisele et al. 2003, Keating et al. 2003, Keating et al. 2004), because it considers user-definable boundaries that can be agreed in a participatory manner on the ground and that can be readily recognized by community-based staff without access to, or the necessary education to use, GIS technology. In this way, GIS can be participatory, with the potential to enhance community involvement (Abbot et al. 1998). In the operational context of malaria control Dar es Salaam, this rather basic but straightforward way of applying GIS is advantageous, as resources in terms of available data and expert personnel are limited. The same tendency has also been observed for lower-income countries in general (Dunn et al. 1999), and accessing such limited resources can be a challenge in itself.

The system of ten-cell-units such as the one in Dar es Salaam (or *hamlets* and *vitongoji*, as they are called in the rural districts of Tanzania (Ifakara Health Research and Development Centre 2005) probably is slightly different to the administrative systems in countries other than Tanzania. Therefore, applying this mapping approach to other regions of Africa and beyond will require the adaptation to the particular systems of each country. In such cases, the smallest administrative units that exist in the respective areas of interest in those countries can be used as adequate substitutes for ten-cell-units. However, for successfully utilizing the participatory mapping procedure, it is of crucial importance that the residents of the target areas are aware of the administrative units they live in. Otherwise, community-based programme staff would not be able to draw from the knowledge of community members regarding the locations of boundaries. Therefore, in areas where the smallest existing administrative units are not well known to the local population, it might be a good alternative to refer to roads, rivers, pathways or similar intuitive landmarks that can be easily identified by community members.

Similar mapping approaches in African settings have been implemented for other purposes, scales and cities. For example, in Southern Sudan, urban maps have been produced to assist town planners in their efforts to respond effectively to returning population and reintegration issues (www.southsudanmaps.org). The Data Exchange Platform for the Horn of Africa

(DEPHA) also provides a few datasets on urban scale (www.depha.org). The EPIDEMIO programme has produced maps of several African cities (www.epidemio.info). However, in contrast to the procedure in Dar es Salaam, these GIS-based approaches required a considerable amount of technical expertise and external support. Moreover, there are no participatory components. Hence, they cannot provide the necessary basis for community-based comprehensive mosquito larval surveillance.

The costs of the mapping approach are listed in Table 5.2. For mapping the entire study area surveyed here, less than US$ 14,000 have been spent, which is equal to US$ 831 per km^2. Thus, the complete set of correct sketch and formal maps covering one TCU costs an average of approximately US$ 24. Considering that the maps have to be produced only once and do not require much updating from then on, these costs appear reasonable and affordable not only for the Dar es Salaam programme, but also for any other comparable larval control intervention in Africa or elsewhere.

Areas that were initially not included in any sketch map are theoretically just as likely as any other area to contain breeding sites for malaria vectors, and might be very important sources for mosquitoes that fly into residential areas. In the study area in Dar es Salaam, most of the newly included areas were industrial or commercial areas and open spaces. Whereas industrial and commercial areas might be just as important as residential ones in terms of mosquito productivity, the open grass and scrublands that often frame such industrial and commercial plots are particularly likely to support key vectors from the *An. gambiae* complex (Briet et al. 2003). This is particularly true for open spaces, notably those that are located in lowlands with a relatively high ground water table, and used for agricultural purposes. Considering that the number of infective mosquito bites per person per year is inversely proportional to the human population density (Killeen et al. 2000, Smith & McKenzie 2004), and mosquitoes disperse until they find blood (Service 1997, Smith et al. 2004), all these predominantly unoccupied areas might therefore contribute considerably to mosquito emergence rate (Eisele et al. 2003, Keating et al. 2004, Killeen et al. 2003, Service 1997, Smith et al. 2004) and malaria transmission (Le Menach et al. 2005) in neighbouring residential TCUs. Therefore, the inclusion of the initially unsurveyed areas into routine mosquito larval surveillance and control is likely to have a great impact on the effectiveness of such a programme, particularly after the planned addition of surrounding wards to the UMCP.

The framework generated through this mapping procedure made it possible to rationally allocate every square meter of the programme area to individual CORPs under the oversight of specific supervisors. Such individualization of responsibility is considered essential for managing larviciding programmes (Killeen et al. 2002, Soper & Wilson 1943) because of the rigorous, sustained and comprehensive coverage required to achieve useful reductions of malaria transmission in Africa.

5.7 Conclusions

The participatory mapping approach developed in Dar es Salaam enables complete coverage of targeted areas with mosquito larval habitat surveillance and control through comprehensive spatial coverage with community-derived maps. It can be fully integrated into an operational malaria control programme which takes local administrative or other suitable structures into account. The procedure is simple, straightforward, and low cost. It requires only minimal technical skills and equipment. Most importantly, even if the respective administrative boundary system varies from country to country, it can easily be scaled up not only to the remaining parts of Dar es Salaam, which is currently in progress, but also to other cities in Tanzania or any country affected by mosquito-borne diseases in Africa or elsewhere.

5.8 Authors' contributions

SD designed and implemented the study, analyzed the results and drafted the manuscript. DN, KK, DM, HM, UF, AWD, MT and MCC participated in designing and implementing the study. GFK conceived the participatory mapping strategy, supported the design and implementation of the study, and assisted in drafting the manuscript. All authors read and approved the final manuscript.

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6 A TOOL BOX FOR OPERATIONAL MOSQUITO LARVAL CONTROL: PRELIMINARY RESULTS AND EARLY LESSONS FROM THE URBAN MALARIA CONTROL PROGRAMME IN DAR ES SALAAM, TANZANIA

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6.1 Abstract

Background

As the population of Africa rapidly urbanizes, large populations could be protected from malaria by controlling aquatic stages of mosquitoes if cost-effective and scalable implementation systems can be designed.

Methods

A recently initiated Urban Malaria Control Programme in Dar es Salaam delegates responsibility for routine mosquito control and surveillance to modestly-paid community members, known as Community-Owned Resource Persons (CORPs). New vector surveillance, larviciding and management systems were designed and evaluated in 15 city wards to allow timely collection, interpretation and reaction to entomologic monitoring data using practical procedures that rely on minimal technology. After one year of baseline data collection, operational larviciding with *Bacillus thuringiensis var. israelensis* commenced in March 2006 in three selected wards.

Results

The procedures and staff management systems described greatly improved standards of larval surveillance relative to that reported at the outset of this programme. In the first year of the programme, over 65,000 potential *Anopheles* habitats were surveyed by 90 CORPs on a weekly basis. Reaction times to vector surveillance at observations were one day, week and month at ward, municipal and city levels, respectively. One year of community-based larviciding reduced transmission by the primary malaria vector, *Anopheles gambiae s.l.*, by 31% (95% C.I.=21.6-37.6%; p=0.04).

Conclusion

This novel management, monitoring and evaluation system for implementing routine larviciding of malaria vectors in African cities has shown considerable potential for sustained, rapidly responsive, data-driven and affordable application. Nevertheless, the true

programmatic value of larviciding in urban Africa can only be established through longer-term programmes which are stably financed and allow the operational teams and management infrastructures to mature by learning from experience.

6.2 Background

With the prospect of more than half of the African population living in urban areas by the year 2030, it is anticipated that the challenge and opportunity for tackling malaria burden in urban areas will also grow (Hay et al. 2005, Keiser et al. 2004, Robert et al. 2003). Compared to rural settings, malaria in urban Africa is generally characterized by lower intensities and more focal distribution of transmission, resulting in weaker immunity in the afflicted population and distribution of disease burden across older age groups (Keiser et al. 2004, Robert et al. 2003). Compared to rural settings, urban areas usually offer more malaria control options because relatively good transport, communication, educational and health infrastructure is available to large populations in small geographic areas. Since there is relatively easy access to most urban area breeding sites, control interventions such as environmental control and larvicide application may be cost-effective (Keiser et al. 2004, Robert et al. 2003), but remain to be rigorously evaluated in the modern African context (Killeen 2003, Killeen et al. 2002, Killeen et al. 2004). Although locally targeted approaches (Smith et al. 2007, Smith et al. 2006, Woolhouse et al. 1997) are desirable, and this may be realizable in the future (Gu & Novak 2005, Gu & Novak 2006, Killeen et al. 2006b, Matthys et al. 2006), all documented successes of larval control against African malaria vectors have depended on rigorous and comprehensive surveillance for aquatic stage mosquitoes (Watson 1953) to enable wholesale suppression (Utzinger et al. 2001) and even elimination (Shousha & Pasha 1948, Soper & Wilson 1943). To be sustainable in the context of African cities today, integrated vector management needs to be implemented through community-based systems using simple tools that are appropriately tailored to the enormous reservoir of affordable labour that is available *in situ* (Barat 2006, Impoinvil et al. 2007, Walker & Lynch 2007).

Although most malaria research has generally focused on rural settings (Hay et al. 2005, Keiser et al. 2004, Robert et al. 2003, Wang et al. 2005), Dar es Salaam in Tanzania is one of the few African cities in which the distinctive characteristics of urban malaria ecology and epidemiology have been examined in depth with useful records dating back almost a century (Castro et al. 2004, Sattler et al. 2005, Vanek et al. 2006, Wang et al. 2006). The main vectors of malaria in the area of Dar es Salaam are *Anopheles gambiae sensu stricto*, *Anopheles arabiensis*, *Anopheles funestus* and *Anopheles merus* (Geissbühler et al. 2007a). *Plasmodium falciparum* is the most common malaria parasite, accounting for 90% of all cases (Castro et al. 2004). Interestingly, malaria vectors in the city appear to have adapted to high coverage with bed nets and improved housing by predominantly feeding outdoors (Geissbühler et al. 2007a). Thus, insecticide-treated nets confer slightly less protection than in rural areas so additional measures directed at aquatic stages of vector mosquitoes may have a useful role in this and similar urban settings (Geissbühler et al. 2007a).

This publication describes the principles and practices of a novel management system for implementing, monitoring and optimizing routine larviciding in African cities that was developed at the City Council of Dar es Salaam in Tanzania. It aims to provide an array of tools which can be adapted to different ecological settings for programmes aiming to integrate anti-larval interventions in ongoing malaria control programmes. Furthermore, preliminary results obtained in the first year of operation are described and the potential of these systems are discussed.

6.3 Methods

Study site

The study was conducted in Dar es Salaam, Tanzania's biggest and economically most important city with 2.7 million inhabitants and a total area of 1400 km^2 (Castro et al. 2004, National Bureau of Statistics 2003). The city is divided into three municipalities, namely Ilala, Kinondoni and Temeke. Each of these municipalities is further divided into wards and then neighbourhoods known as *mitaa* (singular *mtaa*) in Kiswahili, literally meaning street (Dongus et al. 2007).

A recently-initiated Urban Malaria Control Programme (UMCP) in Dar es Salaam delegates responsibility for routine mosquito control and surveillance to modestly paid community members, known as Community-Owned Resource Persons (CORPs) in a decentralized manner (Mukabana et al. 2006). However, baseline evaluation revealed that at the early stage of the UMCP the levels of coverage achieved by the CORPs were insufficient to enable effective suppression of malaria transmission through larval control, and that training, support and supervision of the CORPs was poor (Vanek et al. 2006). The authors concluded that novel surveillance systems were required to enable community-based integrated vector management (Vanek et al. 2006).

Early experience also indicated that control of culicine species, responsible for the bulk of biting nuisance (Bang et al. 1977, Chavasse et al. 1996, Stephens et al. 1995), would be essential to achieve community acceptance and support for the programme. It was therefore decided to prioritize intensive control of malaria vector species in habitats which are open to sunlight (referred to as “open habitats”) but to also implement less intensive control of sanitation structures, such as pit latrines, soakage pits, and container type habitats which are closed to the sun (referred to as “closed habitats”) and produce huge numbers of *Culex* and *Aedes,* but no *Anopheles* (Chavasse et al. 1995a, Chavasse et al. 1995b). Thus, the bulk of the programme description below prioritizes and focuses on the system for controlling open habitats suitable for *Anopheles*, with a brief section describing mosquito control in closed habitats, for which no detailed routine larval surveillance was undertaken.

A strategic overview of the Dar es Salaam Urban Malaria Control Programme (UMCP)

Fifteen wards were included in the Dar es Salaam UMCP (Figure 6.1) encompassing as wide a variety of malariological situations as possible. In total an area of 55 km^2 is covered with wards ranging from 0.96 to 15 km^2 in size. In 2002, 611,871 people, representing 23% of the urban population, lived within this area (National Bureau of Statistics 2003) which covers 4% of the surface area of urban Dar es Salaam. By April 2007 all 15 wards had been mapped in detail as a precursor to systematic larviciding (Dongus et al. 2007). Acronyms and other specific terminology are defined and explained in Table 6.1. The Dar es Salaam UMCP was conceptualized and developed according to the key principles listed in Table 6.2 which were formulated on the basis of direct practical experience (Fillinger et al. 2003, Fillinger & Lindsay 2006, Fillinger et al. 2004, Mukabana et al. 2006, Opiyo et al. 2007, Sattler et al. 2005, Vanek et al. 2006) and an extensive literature review (Killeen et al. 2002, Killeen et al. 2004, Killeen et al. 2006b, Mukabana et al. 2006).

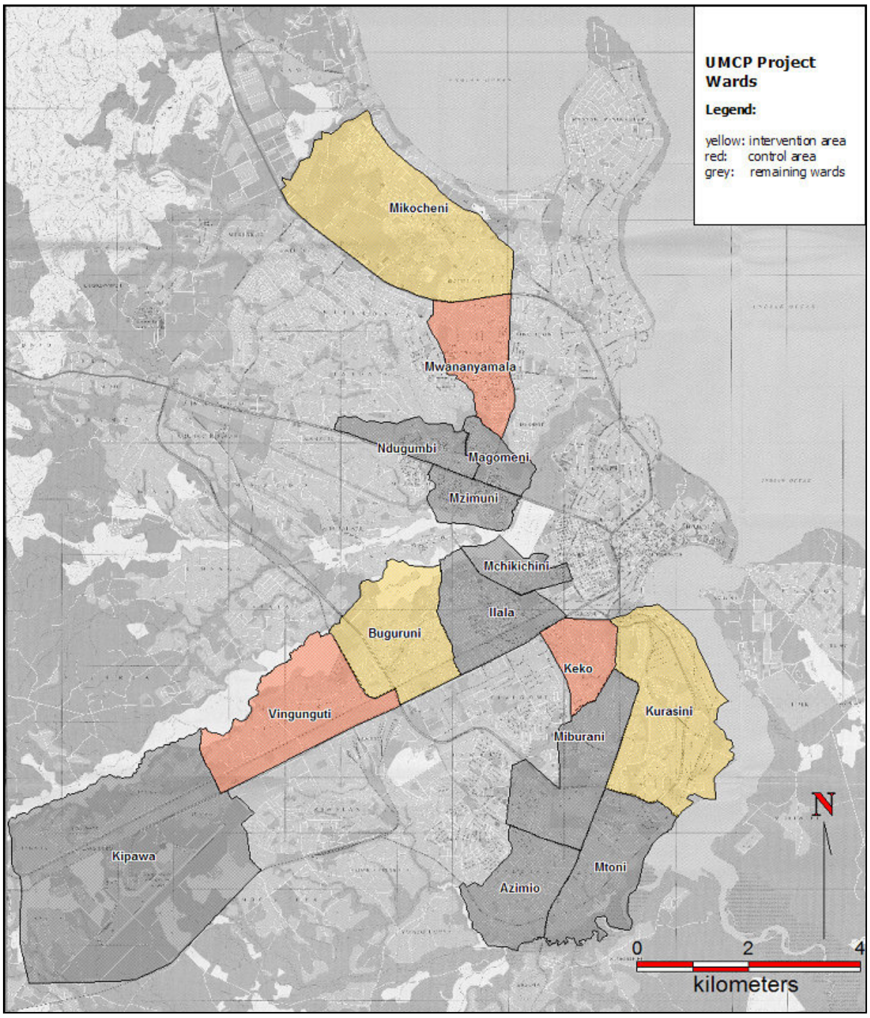

Figure 6.1: Wards included in the study area of the Dar es Salaam Urban Malaria Control Programme (UMCP)

UMCP wards; specifying those targeted for larviciding from March 2006 onwards (intervention), those considered to be the most comparable control (non-intervention wards) and those remaining.

Table 6.1: Definitions and abbreviations

Closed habitat	Any stagnant or slow-flowing water body which is not exposed to the sun and therefore unlikely to produce *Anopheles* malaria vectors but may produce culicines, notably abundant *Culex quinquefasciatus* (Chavasse et al. 1995a, Chavasse et al. 1995b).
CORP	Community-Owned Resource Person. The responsibility for routine mosquito surveillance and application of larvicide is delegated to CORPs, who are individual community members appointed and managed through neighbourhood health committees (Mukabana et al. 2006).
GIS	Geographical Information System. GIS is a set of tools for capturing, storing, retrieving, transforming and displaying spatial data.
GPS	Global Positioning System. An operational system that allow receiving and converting signals from satellites to a specific position on Earth.

Municipality	The Dar es Salaam City Region is subdivided into three municipalities (the equivalent term for districts in urban Tanzania), namely Ilala, Temeke and Kinondoni.
Neighbourhood	The 73 wards of the Dar es Salaam City Region are administratively subdivided into 368 neighbourhoods. The 15 wards covered by UMCP comprise 67 neighbourhoods. The local Kiswahili term for neighbourhood is *mtaa* (plural *mitaa*) which literally means “street”.
Open habitat	Any stagnant or slow-flowing water body which is openly exposed to sunlight, even if only partially and for a portion of the day. These constitute potential habitats for malaria vector *Anopheles* mosquitoes (Gillies & De Meillon 1968, Holstein 1954), as well as a variety of culicines.
Plot	All TCUs within the wards covered by the UMCP are subdivided into plots. A plot is defined here as a specific physical area with an identifiable owner, occupant or user and with clearly defined boundaries within one specific TCU. The plot boundaries are defined by UMCP staff. Therefore, the plots do not always correspond to actual cadastral information such as land ownership.
Region	The United Republic of Tanzania is divided into 26 administrative regions, of which Dar es Salaam city and its associated hinterland is one.
TCU	Ten-Cell-Unit. The 368 neighbourhoods (*mitaa*) of the Dar es Salaam City Region are subdivided into several thousand ten-cell-units (TCUs). These are the smallest units of local government, headed by a locally elected chairperson. In principle, TCUs should comprise ten houses each but are typically larger in practice and sometimes exceed one hundred houses.
UMCP	Urban Malaria Control Programme of the Dar es Salaam City Medical Office of Health, developed in co-operation with national and international research and funding organizations.
Ward	The three municipalities of the Dar es Salaam City Region are subdivided into 73 administrative sub-units known as wards. Currently, 15 of these wards are covered by the UMCP.

Table 6.2: Conceptual principles underlying development of the Dar es Salaam Urban Malaria Control Programme

Rapid response	*An. gambiae* sibling species readily develop from egg to adult within a week in habitats that often occur transiently and unpredictably (Gillies & De Meillon 1968, Holstein 1954) so surveillance and larvicide application must be implemented in cycles of a week or less, with consequent responses to observed failures executed within 24 hours (Fillinger & Lindsay 2006, Soper & Wilson 1943, Watson 1953).
Community-based implementation	Sustainable programmes in Africa will be predominantly staffed by community-based personnel with minimal educational qualifications (Mukabana et al. 2006, Mutuku et al. 2006, Townson et al. 2005, van den Berg & Knols 2006), so simple protocols and readily-verifiable targets that can be managed with minimal technology are essential to achieve effectiveness (Killeen et al. 2006b).
Decentralization	Given these resource limitations and the sheer abundance of mosquito aquatic habitats in tropical Africa, responsibility for surveillance and response to operational monitoring observations must therefore be devolved to staff assigned to geographic sub-units small enough to be traversed daily on foot.

Comprehensive coverage	Until reliable, generalizable and practical procedures are developed which allow targeting of the most productive malaria vector habitats (Gu & Novak 2005, Gu & Novak 2006) under such programmatic circumstances, high coverage of all potential sources (Killeen 2003, Killeen et al. 2002, Shousha & Pasha 1948, Soper & Wilson 1943, Utzinger et al. 2002, Utzinger et al. 2001, Watson 1953) is necessary to achieve satisfactory reductions of malaria transmission and burden in African settings (Killeen et al. 2006a, Killeen et al. 2006b).
Rigorous vertical management	To achieve sufficient coverage, such decentralized, community-based approaches will require new tools for hierarchical, centralized management that individualize responsibility for all program activities (Killeen et al. 2002, Soper & Wilson 1943) and allow rigorous monitoring, evaluation and adaptive tuning (Vanek et al. 2006). Each level of management from the CORPs up to the City Mosquito Control Coordinator is responsible for identifying and addressing all programmatic shortcomings under their purview before they are detected by the next highest level within the program or external evaluators such as donors or research partners.
Adult mosquito densities as a priority performance indicator	Larval surveillance alone is inadequate to monitor or evaluate larviciding programs because it only reflects observations in habitats successfully covered by surveillance activities. Weekly monitoring of adult mosquitoes is necessary to allow rigorous monitoring, evaluation and management. While clinical or parasitological indicators are essential for rigorous evaluation of program impact, these are usually collected and reported on timescales too slow to enable day-to-day management for optimal performance.
Separation of surveillance and treatment responsibilities	Larvicidal treatment, monitoring and evaluation activities should each be implemented by distinct groups of personnel so that competing interests in data collection and interpretation are minimized (Killeen et al. 2002, Soper & Wilson 1943, Watson 1953)
Integration with existing infrastructure and governance mechanisms	Larval control programs must be integrated with pre-existing local government structures and public health systems to minimize costs, maximize effectiveness and ensure sustained acceptance by communities, public services and governments (Mukabana et al. 2006, Mutuku et al. 2006, Townson et al. 2005, van den Berg & Knols 2006).
Full time staff	Larval control program staff must be allocated to the program full time. New responsibilities can not be taken over by established and often overburdened public health staff. Larval control staff will be recruited and managed through existing infrastructure and governance mechanisms as described above.
Satisfactory evidence must precede scale up.	Although some encouraging evidence does exist (Fillinger & Lindsay 2006, Shousha & Pasha 1948, Soper & Wilson 1943, Utzinger et al. 2002, Utzinger et al. 2001, Watson 1953), strategies targeting aquatic stage mosquitoes, including systematic larviciding remain underdeveloped and have yet to be evaluated on scales that are meaningful for scale-up as priority malaria prevention measures in Africa.

Basis: Direct practical experience (Fillinger et al. 2003, Fillinger & Lindsay 2006, Fillinger et al. 2004, Mukabana et al. 2006, Opiyo et al. 2007, Sattler et al. 2005, Vanek et al. 2006) and extensive literature review (Killeen et al. 2002, Killeen et al. 2004, Killeen et al. 2006b, Mukabana et al. 2006)

The reporting structure of the UMCP consists of a matrix of activities which are hierarchically layered over a range of spatial and administrative scales (Figure 6.2). At each spatial and administrative scale, the programme reports to relevant stakeholders but remains essentially autonomous in terms of day-to-day activities. Importantly, lines of reporting are carefully designed with respect to the guiding principles of Table 6.2 so that competing interests of staff are minimized with respect to their implementation, support and supervision duties. For example, CORPs responsible for larval surveillance, and those responsible for the application of larvicides, report separately to their ward supervisors. Furthermore, adult mosquito surveillance is implemented by a separate team which primarily reports to the city mosquito control coordinator and secondarily to the three municipal coordinators so that this data reporting line is collected and reported independently of staff responsible for maintaining low vector densities. The implementation of each activity, as well as their integration into a coordinated management system is described in detail below. All data sheets and standard operating procedures were translated in Kiswahili to ease the work of community-based staff.

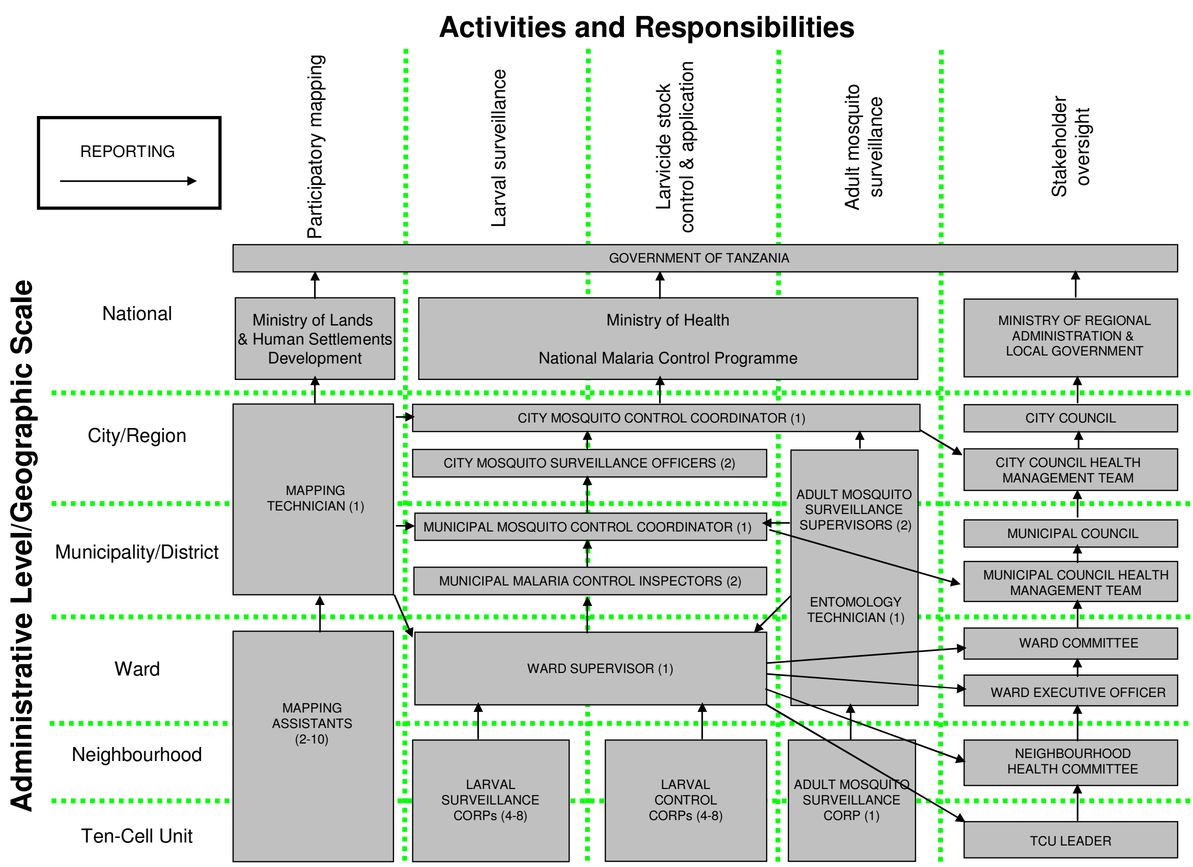

Figure 6.2: Reporting structure of the UMCP

Presented as a matrix of activities which are hierarchically layered over a range of spatial and administrative scales. The numbers presented in brackets describe the number of personnel assigned to each post in each administrative subunit rather than level (e.g. 2 municipal inspectors at each of 3 municipalities means that a total of 6 should be working for the programme at any time).

Participatory mapping

Although the use of remote sensing techniques for the detection of mosquito breeding habitats have proven useful (Mushinzimana et al. 2006), a large number of *An. gambiae* larval habitats are temporary and appear and disappear frequently in space and time especially in the urban context, which requires constant supervision. Maps of habitats need to be developed and updated on a weekly basis to keep up with the rapidly changing field situation. In this scenario, the use of remotely sensed imagery to accurately monitor habitats demands the analysis of images at multiple times, which is likely to face financial and technical (e.g. cloud coverage) constraints.

Before any surveillance or control activities can be successfully implemented, the boundaries of all targeted areas must be mapped thoroughly in a way that is useful to both the highest levels of city management and the community-based staff responsible for executing most of the programme's activities. A simple community-based mapping procedure that requires no electronic devices in the field was, therefore, developed (Dongus et al. 2007), which formalizes ground-based sketch maps using laminated aerial photographs in the field and then digitizes them using Geographical Information Systems (Figure 6.3). Initial estimates from the first three wards mapped indicated that over 30% of the study area had not been included in the first round of sketch mapping by larval surveillance CORPs, mostly because they were non-residential or industrial areas that do not exist on local government residential lists (Dongus et al. 2007). This procedure, described in detail elsewhere (Dongus et al. 2007), allows rapid identification and inclusion of these key areas for sketch mapping and routine mosquito control, as well as more equal distribution of work to field staff.

A key feature of this mapping procedure is that it allows every square meter of the study area to be assigned to a specific geographic unit known as a Ten Cell Unit (TCU) and a specific subunit within that TCU referred to as a plot (Dongus et al. 2007). This in turn allows each of the constituent TCUs in each ward and neighbourhood to be assigned to specific individual CORPs for weekly larval surveillance and larvicide application. Crucially, plots are small enough to allow unambiguous description of individual habitats by CORPs and subsequent identification by supervisory staff in the field. This can be achieved by using a larval habitat surveillance form in conjunction with the corresponding TCU sketch map and plot description form[19]. This mapping procedure provides an essential frame of reference for weekly routine mosquito surveillance and insecticide application, as well as the supervision of these activities by management staff.

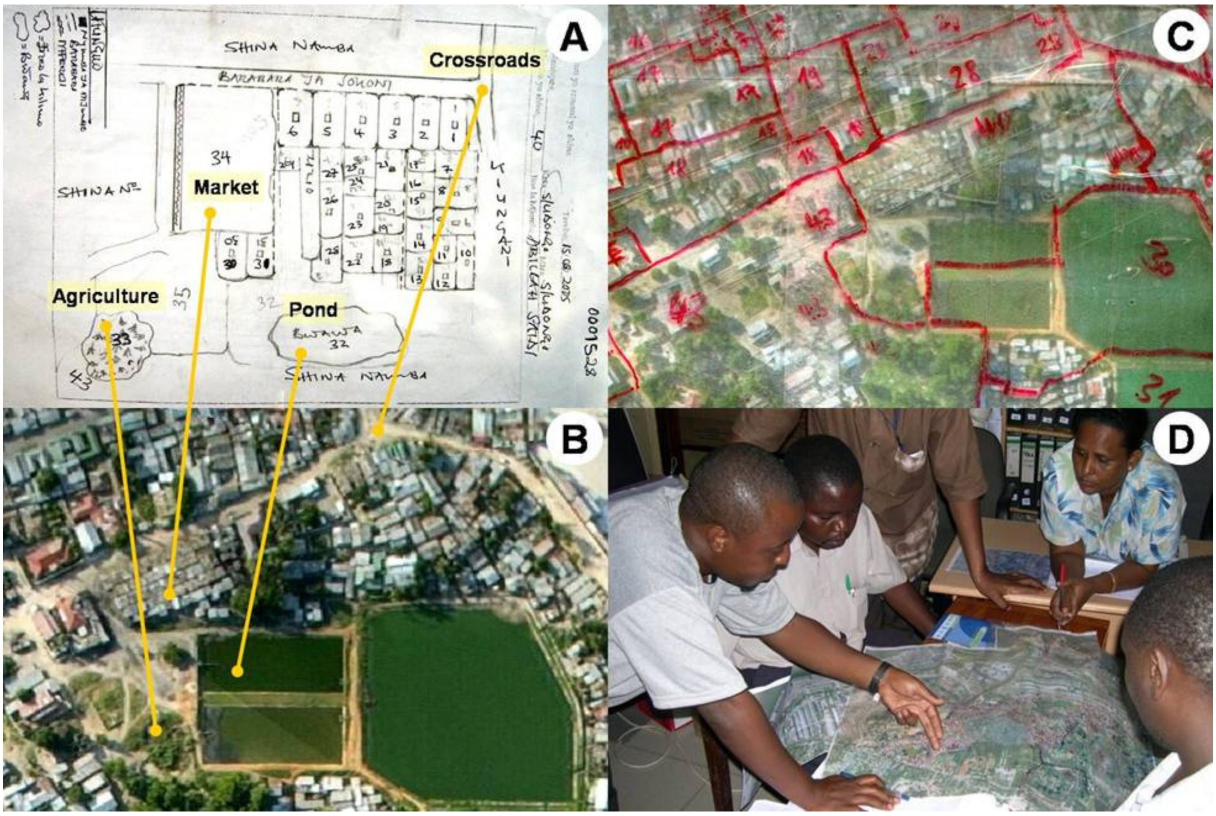

Figure 6.3: Example of a sketch map, aerial picture and field map

A. Sketch map of TCU no. 40 in Kurasini ward, Shimo la Udongo neighbourhood, as drawn by the responsible CORP. Features comprise plots with continuous numbering, streets, drains, agricultural areas and ponds. B. The same area on an aerial picture. The yellow lines connect identical features on the sketch maps and the aerial picture. C. The same area on the laminated map used in the field. The features to be mapped (TCU boundaries and numbers) were marked with non-permanent red marker pens. D. Project management team discussing over the field map of a whole ward, and deciding on necessary follow-up actions. Reproduced from Dongus et al. (2007) (chapter 5).

[19] The published version of this paper contains links to additional files, which are not directly relevant in the context of the thesis. The files are available for download at the journal's website as low-resolution Adobe Acrobat® files but can also be obtained as editable Microsoft Office files from the authors in CD or DVD format so that they can be adapted to alternative settings.

Additional file 1: *Participatory mapping guidelines and TCU mapping and description forms*. The document presents the standard operating procedures and data collection forms used for habitat mapping in the UMCP, Dar es Salaam. (http://www.malariajournal.com/content/supplementary/1475-2875-7-20-s1.pdf)

Surveillance of potential *Anopheles* habitats

All essential standard operating procedures, posters and forms for adapting and reproducing the larval surveillance systems described below are available as an online supplement[20]. Approximately 90 larval surveillance CORPs were employed at any given time during the study and these were each assigned defined areas based initially on local knowledge of habitat abundance, difficulty of terrain and geographic scale of their own neighbourhoods. This workload was subsequently redistributed following detailed participatory mapping (Dongus et al. 2007). In general, CORPs were recruited through local administrative leaders known as street chairmen and received minimal emoluments (Tanzanian Shillings (TShs) 3,000/day or US$ 2.45/day) as volunteer workers through a system developed by the municipal councils of Dar es Salaam for sundry small-scale maintenance tasks such as road cleaning (Mukabana et al. 2006, Vanek et al. 2006). All CORPs are assigned to a single neighbourhood or subset of TCUs from that neighbourhood (Dongus et al. 2007) under the oversight of a single supervisor for the entire ward. CORPs follow predefined schedules of TCUs which they are expected to survey each day of the week, collecting forms from their ward supervisor at the Ward Executive Office each morning and returning them each afternoon. The return of forms each afternoon is normally used to discuss the day's observations so that the supervisor can follow these up in a timely manner. The schedule of TCUs visited by surveillance CORPs follows one day after the application of microbial insecticides so that indicators of operational shortcoming, such as the presence of late-stage (3rd or 4th instar) mosquito larvae, can be reacted to in sufficient time to prevent unwanted emergence of adult mosquitoes.

[20] Additional file 2: *Larval surveillance guidelines and standard operating procedure for open habitats*. The document presents the standard operating procedures developed for weekly mosquito larval surveillance. (http://www.malariajournal.com/content/supplementary/1475-2875-7-20-s2.pdf)

Additional file 3: *Posters describing categories for open habitats*. The file shows a poster developed for training ward based staff on identification of open, sun exposed mosquito breeding sites. (http://www.malariajournal.com/content/supplementary/1475-2875-7-20-s3.pdf)

Additional file 4: Posters describing categories for closed habitats. The file shows a poster developed for training ward based staff on identification of closed mosquito breeding sites. (http://www.malariajournal.com/content/supplementary/1475-2875-7-20-s4.pdf)

Additional file 5: *Larval surveillance forms for open and closed habitats*. The document presents all data collection sheets used by ward and city based staff for mosquito larval surveys. (http://www.malariajournal.com/content/supplementary/1475-2875-7-20-s5.pdf)

Additional file 6: *Training presentation for larval surveillance*. The document shows a training presentation for ward based staff on how to recognize mosquito larval habitats and how to characterise them according to the standard operating procedures. (http://www.malariajournal.com/content/supplementary/1475-2875-7-20-s6.pdf)

Every potential *Anopheles* habitat found in each plot is described by using a standardized form and classified as one of the following habitat types: 1: Puddles & tyre tracks, 2: Swampy areas, 3: Mangrove swamps / Saltwater marshes 4: Drains/Ditches, 5: Construction pits/foundations/man-made holes, 6: Water storage containers, 7: Rice paddies, 8: Ridge and furrow agriculture known as *Matuta*, 9: Habitats associated with other agriculture, 10: Streams/river beds, 11: Ponds, 12: Others. It is important to note that once a habitat is identified and assigned a habitat identification number, that number is retained for all subsequent rounds of surveillance so that a) the identity of those habitats can be unambiguously allocated and followed up in the field and b) the dynamics of larval populations in habitats of different types and characteristics can be assessed. Thus, when habitats contain no water, they are still recorded but described as being dry. The presence of mosquito larvae and pupae are determined by dipping potential breeding sites (Service 1993). Up to 10 dips are taken with a white 350ml dipper. Anopheline and culicine larvae are differentiated macroscopically in the dipper according to whether they float parallel with the water surface (anophelines) or hang down from the surface (culicines) (Rozendaal 1997). No further differentiation to species level is attempted. Records on presence or absence are taken for both genera separately. If larvae are present the sizes of the larvae are observed and classified as early (1st and 2nd instars) or/and late (3rd and 4th instars) stages. Morphological differentiation of pupae from different genera is very difficult and impracticable under field conditions in an operational malaria control programme implemented by staff with basic training (Fillinger et al. 2004, Sattler et al. 2005). Pupae are, therefore, not differentiated between *Anopheles* and other genera. The approximate size, depth and associated vegetation for each habitat are also recorded.

The characteristics of the CORPs forms are also captured in the corresponding forms used by Municipal Mosquito Control Inspectors (MMCIs) who assure quality control of CORPs work independently of their ward supervisors (Figure 6.4). All MMCIs conduct weekly spot checks of six randomly assigned TCUs in their municipality , assessing the accuracy of the data collected by the CORP through direct on-the-spot observation. Spot checking of six TCUs takes approximately two days per week allowing enough time for the implementation of other duties e.g. supervision of data collection and training activities nevertheless ensuring that each larval survey CORP is visited at least once every two months. Additional larval habitats identified by the MMCI that had not been detected by the CORPs are recorded and additional clear discrepancies between the records of the CORPs and the observations of the inspector documented. It should be noted that although the observations of the inspectors are shared with the respective ward supervisors, they are primarily reported to the Municipal Mosquito Control Coordinator who takes responsibility for managing the Ward Supervisors.

Larvicide application and stock management

After one year of baseline data collection on habitat and larval seasonality and adult abundance the UMCP staff reviewed the performance of larval surveillance CORPs and Ward Supervisors for all 15 wards in order to select one ward from each municipality for larval control interventions in the following year. The research team based the decision of which wards will receive larviciding and which wards will be compared with the intervention wards mainly on the proven ability of the ward supervisors and ward-based CORPs to implement the required task. Specifically, their ability to collect, understand, use and submit high quality data during the baseline data collection period was the primary criterion for choosing these high priority wards. Since the success of larval control interventions largely depends on good management skills and supervision, the UMCP team selected the best performing wards for the evaluation of the first year's intervention, whilst also striving to improve the performance of the remaining wards. One ward from each municipality, namely Buguruni, Mikocheni and Kurasini, were chosen for larviciding. In an attempt to facilitate representative comparison and analysis, one non-intervention ward from each municipality, namely Vingunguti, Mwananyamala and Keko, were selected *a priori* on the same basis as the intervention wards. Along with the intervention wards, these non-intervention wards were targeted for particularly rigorous maintenance of larval surveillance standards so that valid evaluations of larvicide impact upon larval populations could be made. This choice of a limited number of controls (non-intervention wards) was considered essential to ensure that the laboriously-collected larval data from both, intervention and non-intervention areas, were similar in terms of their extent and intensity for the first year's evaluation. In parallel, all remaining wards were subsequently evaluated and targeted for re-training activities or staff replacement, so that by the end of March 2007 all wards showed comparable performance.

Larviciding is implemented exclusively with microbial insecticides, specifically *Bacillus thuringiensis* var. *israelensis* strain AM65-52 (*Bti*; VectoBac® Valent BioSciences Corporation, VBC, USA) and *Bacillus sphaericus* strain 2362 (*Bs*; VectoLex®, VBC, USA) because they are 1) highly efficacious against African malaria vectors, 2) selective in action,

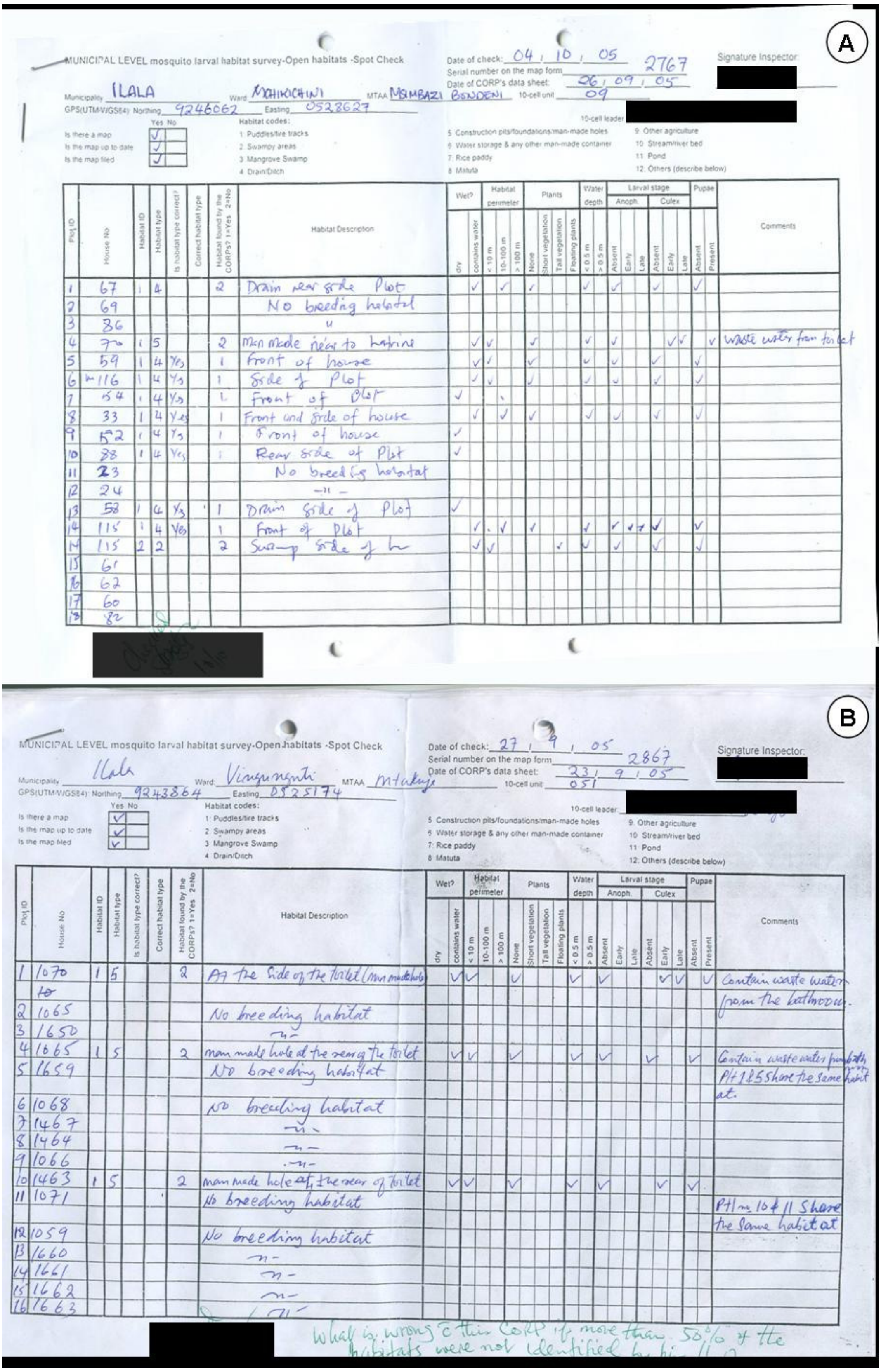

Figure 6.4: Examples of spot-checking forms for Municipal Mosquito Control Inspectors

A. A typical example signed on the bottom left by a City Mosquito Surveillance Officer to show it has been checked for consistency and signs of problems requiring corrective action by management at city, municipal and ward level. B. An example of where an inspector has found poor coverage of potential habitats for *Anopheles* larvae by a CORP but failed to highlight it or record any corrective action. Note the query of the City Mosquito Surveillance Officer at the bottom.

3) environmentally safe to non-target organisms, 4) unlikely to result in resistance when used in combination or when only *Bti* is used, 5) safe for human handling and consumption, 6) easy to handle by staff with minimal training and protective measures, and 7) their impact can be easily monitored (Fillinger et al. 2003, Fillinger & Lindsay 2006, Majambere et al. 2007, Rozendaal 1997, Shililu et al. 2003, WHO 1999). *Bti* is efficacious in all types of habitats but is less potent in high concentrations of organic matter, such as open sewers, and closed habitats, such as pit latrines and septic tanks. *Bti* needs to be applied weekly, but is relatively cheap compared with *Bs* (Fillinger & Lindsay 2006). Nevertheless, *Bs* has the advantage of being efficacious in very polluted water and even recycling by propagating itself in the cadavers of the mosquito larvae it kills (Charles & Nicolas 1986, Hougard 1990, Karch et al. 1990, Matanmi et al. 1990, Pantuwatana et al. 1989, Skovmand & Bauduin 1997, Sutherland et al. 1989). Although *Bs* can have a residual effect and may not require weekly application, its efficacy in open habitats is difficult to predict. Furthermore, the habitat monitoring requirements to enable timely re-application and the decision making process necessary to decide when and where to apply a larvicide with residual effect might be a source for errors. Therefore, the application of *Bs* was not considered appropriate for the start of a programme. Moreover, *Bs* formulations are about three times more expensive than *Bti* formulations (Fillinger & Lindsay 2006) and need to be applied in higher dosages to produce a persistent residual effect (Fillinger et al. 2003) which is likely to be less cost-effective than labour intensive treatment with *Bti* (Worrall 2007). In closed habitats which are not exposed to solar radiation and support densities of culicine mosquitoes that are high enough to enable sustained recycling, a single treatment with a sufficient dosage of *Bs* can be reliably expected to suppress emergence for several weeks (Gunasekaran et al. 1996, Hougard et al. 1993, Lago et al. 1991, Sutherland et al. 1989).

Two formulations of larvicides are used in the programme: water-dispersible granules (WDG) are applied as aqueous suspensions using Solo® 475 knapsack sprayers, whereas corn granules (CG) are applied by hand. CG was preferred for the vast majority of habitats that are open to the sun. Although hand application of CG treats large areas less rapidly and less evenly than WDG, it is broadly applicable under different environmental conditions. Moreover, it can be readily applied by community-based personnel with minimum training. Granules can penetrate vegetation to reach targeted water surfaces and can be distributed further than liquid aerosols, thereby allowing treatment of less accessible sites. CG was also preferred for treating closed habitats because it is easy to apply to such domestic mosquito sources by CORPs and even the house owners. Liquid application of WDG with knapsack sprayers was preferred for extensive areas of stagnant water with little emergent or floating vegetation that might prevent the sprayed aerosol from reaching the water surface.

Based on evaluations of *Bti* and *Bs* in western Kenya (Fillinger et al. 2003, Fillinger & Lindsay 2006), the formulations-dosage combinations described in Table 6.3 were recommended for larval control, although in practice these dosages were often accidentally exceeded especially by inexperienced staff and in very small habitats. Training materials and detailed guidelines for insecticide application, based on locally implemented calibration exercises, were prepared in a participatory manner and refined through early field piloting[21]. While open habitats with the potential to produce *Anopheles* are treated weekly by Mosquito Control CORPs assigned to neighbourhoods or portions of neighbourhoods, closed habitats are treated every three months by small teams of additional CORPs working through entire wards on a quarterly cycle.

The specificity of these microbial insecticides makes stock control substantially easier because they do not have any uses, other than mosquito control, which avoids financial incentive for theft, misuse or misappropriation. Nevertheless, insecticide stocks are carefully managed at a central storage site and distributed to locked cabinets in each ward office on a weekly basis. Insecticide stocks are distributed on a ‘first-in, first-out’ basis and decentralized stocks at the ward level are replenished weekly on the basis of consumption and projected need. Simple, but readily verifiable records of the daily use of insecticide by each individual CORP allows decentralized detection and correction of inappropriate use rates by Ward Supervisors and other management personnel in a manner similar to programmes for indoor residual spraying of chemical insecticides in southern Africa (Booman et al. 2003). Consumption rates at the ward level can also be reconciled with city level records at the central storage and delivery facility. These central stock management procedures also allow timely ordering of new stock which is currently sourced from the USA and therefore entails a delay of at least two months between ordering and delivery by surface freight.

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[21] Additional file 7: *Guidelines for larvicide application*. The document presents information on microbial larvicides, calibration and the standard operating procedures developed for weekly larvicide application. (http://www.malariajournal.com/content/supplementary/1475-2875-7-20-s7.pdf)

Additional file 8: *Training presentation for larvicide application*. The document shows a training presentation for ward and city based staff on how to apply microbial larvicides. (http://www.malariajournal.com/content/supplementary/1475-2875-7-20-s8.pdf)

Table 6.3: Formulation-dosage combinations recommended to UMCP staff to achieve 100% control of mosquito larvae within 24 hours

Product[a]	Active Ingredient[b]	Dosage kg/hectare	Dosage g/m^2	Application Cycle
Open habitats [c]				
VectoLex® WDG (650 ITU/mg)	Bs	2.0	0.20	1 week
VectoBac® WDG (3000 ITU/mg)	Bti	0.4	0.04	1 week
VectoLex® CG (50 ITU/mg)	Bs	30	3	1 week
VectoBac® CG (200 ITU/mg)	Bti	10	1	1 week
Closed habitats [c]				
VectoLex® CG (50 ITU/mg)	Bs	10	1	3 months

[a] ITU = International Toxic Units, describes the potency of larvicide, the higher the number, the more toxic is 1mg the less is needed to kill 100% of larvae within 24hrs
[b] *Bti* ; *Bacillus thuringiensis* var *israelensis*, *Bs* ; *Bacillus sphaericus*
[c] See Table 6.1 for definitions.

Adult mosquito surveillance

It was originally planned that the CORPs would also report densities of adult mosquitoes at sentinel sites distributed throughout the study area using Mbita-design bed net traps (Mathenge et al. 2002, Mathenge et al. 2005, Mathenge et al. 2004). However, 181 full night samples with these traps executed over two months yielded over 4,000 *Culex*, *Mansonia* and *Aedes* of various species, but only one *An. gambiae sensu lato* caught in one of the traps placed outdoors. While the very low sensitivity of Mbita traps is consistent with other reports (Laganier et al. 2003), additional observations suggest a broader limitation to existing trapping methods for malaria vectors in Dar es Salaam. Further investigation showed that CDC light traps beside occupied bed nets, indoor pyrethrum spray catch and Mbita bed net traps all failed to catch significant numbers of *Anopheles* indoors in Dar es Salaam, while three nights of outdoor human landing catch at one location yielded 136 *An. gambiae s.l.*, 30 other *Anopheles* and 806 culicines, two nearby Mbita traps (one placed indoor and another outdoor) caught only 176 culicines and no *Anopheles* on the same nights. Two nearby CDC-light traps placed beside occupied untreated bed nets (one indoors and one outdoors), which is normally a reliable trapping method for malaria vectors in sub-Saharan Africa (Mathenge et al. 2005), captured 423 culicines, but only three *An. gambiae s.l.* and 14 other *Anopheles*.

Notably, all *An. gambiae s.l.* caught in light traps were found in traps placed outdoors and it has since been shown, through detailed behavioural studies, that *An. gambiae* and *An. arabiensis* are both predominantly exophagic in this highly urbanized environment (Geissbühler et al. 2007a). The inability of CDC light traps and pyrethrum spray knockdown to capture *An. gambiae s.l.* in modern Dar es Salaam contrasts with previous programmes up to 1996, suggesting that this behavioural shift is a relatively recent adaptation, possibly resulting from increased bed net use and house screening.

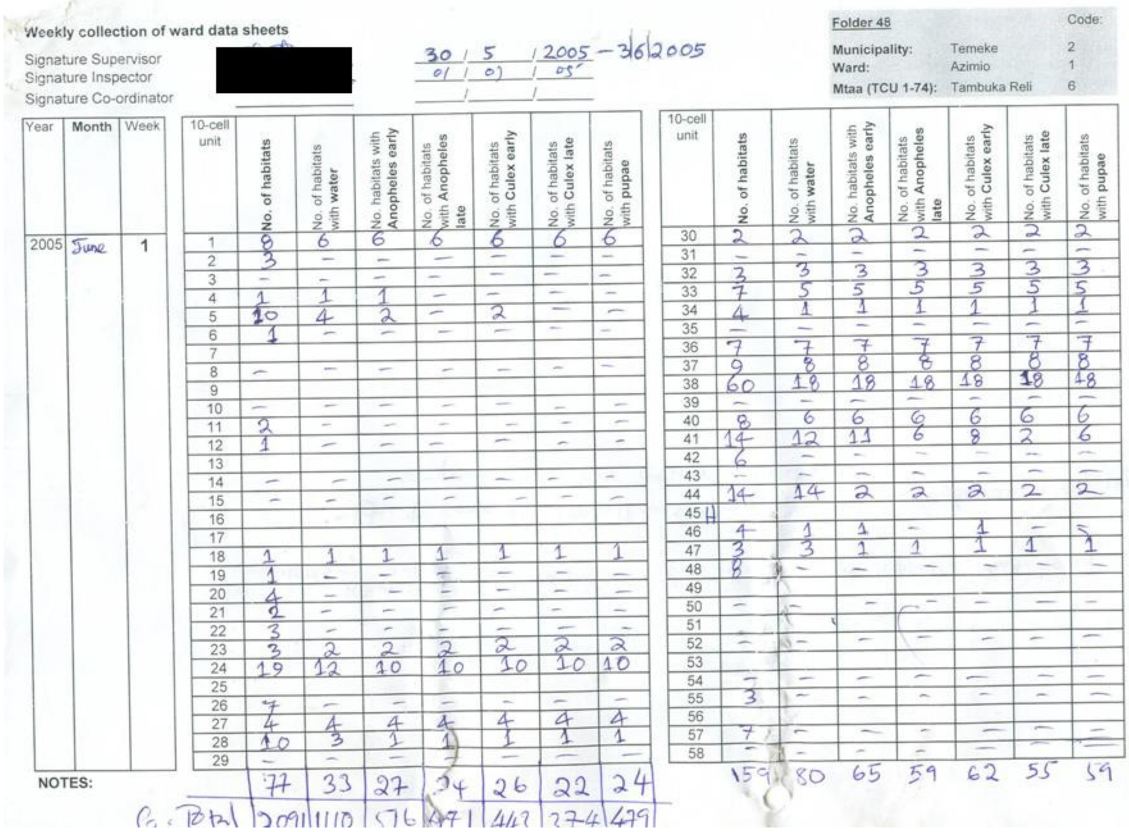
This unexpected difficulty in monitoring adult mosquitoes was overcome by conducting human landing catches as an interim monitoring and evaluation measure while alternative trapping technologies were developed to replace it. Detailed protocols and training materials for the adult mosquito surveillance procedures are not provided for adaptation elsewhere because this cannot be considered a routine procedure for wide-scale programmatic use. The potential health risks associated with human landing catches necessitate careful consideration, justification and ethical review. The human landing catches executed in these early stages of the Dar es Salaam UMCP are undertaken as an interim research tool only. Practical, safe and effective new surveillance procedures have since been developed to prototype stage and will be reported elsewhere after full evaluation in terms of efficacy and effectiveness (NJ Govella, personal communication).

The procedures applied to monitor and evaluate mosquito densities (Geissbühler et al. 2007a) are described briefly as follows. One resident was recruited from each of the 67 neighbourhoods in the study area and employed as an Adult Mosquito Surveillance CORP to conduct one full night of human landing catch each week. All human landing catches are done outdoors. Each CORP is assigned four sampling sites which are distributed approximately evenly across his neighbourhood. For safety reasons, these are typically within walled compounds but are nevertheless chosen on the basis of not only the location, but also the co-operation of the residents and accessibility of the site to city-level supervisors for unannounced spot checks. Once every four weeks at each location, human landing catch are conducted from 6 pm to 6 am for 45 minutes of each hour, allowing 15 minute breaks for rest. Each afternoon a city level team led by two Adult Mosquito Control Supervisors distributes a kit to each CORP scheduled to work that night. The kit consists of netting-covered cups for each hour's catch, an aspirator and a simple form upon which each hour's catch can be recorded so that, upon random inspection at any hour of the night, the recordings and content of the cup can be reconciled. Each morning the kits, with all caught mosquitoes in their respective cups, are collected and returned to a central laboratory. All collected mosquitoes are identified morphologically to genus and, in the case of *Anopheles*, to species complex level (Gillies & De Meillon 1968). Members of the *An. gambiae* species complex are further resolved to sibling species level by polymerase chain reaction (Scott et al. 1993). The sporozoite infection status of each mosquito gets determined by enzyme-linked immuno-absorbent assay (Burkot et al. 1984).

Integration and coordination

Larval surveillance data are primarily summarized and interpreted at the level of the Ward Supervisors to enable the rapid response of larvicide application to observed operational failures. This is accomplished in a practical, affordable and scaleable manner using weekly summary forms[22], which are filled out each afternoon by the supervisor when the Larval Surveillance CORPs under his/her oversight return the filled forms from their work that morning. The total number of habitats and the subset of those which contain water and mosquito larvae of various stages are totalled from each form (and the TCU it represents) provided by the CORPs by simply counting the number of ticks in each column (see Figure 6.4 which closely resembles the equivalent form for CORPs). These totals are then entered in the supervisor's weekly summary sheet, inspected immediately for signs of poor larvicide application, and totalled for each neighbourhood when all its TCUs have been completed (Figure 6.5). Supervisors are expected to note any such indicators of programme failure and consequent follow-up action on these forms, signing and dating all such notes, as well as the confirmation that they have read and checked the form before filing. This approach formalizes the obligation to read and respond to all larval surveillance data within 24 hours, and allows unambiguous assessment of performance and responsibility by municipal and city-level management. Furthermore, it simplifies, accelerates and decentralizes an otherwise vast data aggregation burden without using any computing technology beyond that provided by a pocket calculator.

[22] Additional file 9: *Ward-level weekly summary form for larval surveillance data and form checklist for collation in pre-labelled folders and evaluation by municipal management.* The document shows the data collection form used to prepare a weekly summary of the number of aquatic habitats and their colonisation with mosquito larvae. (http://www.malariajournal.com/content/supplementary/1475-2875-7-20-s9.pdf)



Weekly collection of ward data sheets

Signature Supervisor [redacted] 30 / 5 / 2005 – 3/6/2005

Signature Inspector 01 / 0) / 05

Signature Co-ordinator __ / __ / __

Folder 48 — Code:
Municipality: Temeke — 2
Ward: Azimio — 1
Mtaa (TCU 1-74): Tambuka Reli — 6

Year	Month	Week	10-cell unit	No. of habitats	No. of habitats with water	No. habitats with Anopheles early	No. of habitats with Anopheles late	No. of habitats with Culex early	No. of habitats with Culex late	No. of habitats with pupae
2005	June	1	1	8	6	6	6	6	6	6
			2	3	–	–	–	–	–	–
			3	–	–	–	–	–	–	–
			4	1	1	1	–	–	–	–
			5	10	4	2	–	2	–	–
			6	1	–	–	–	–	–	–
			7							
			8	–	–	–	–	–	–	–
			9							
			10	–	–	–	–	–	–	–
			11	2	–	–	–	–	–	–
			12	1	–	–	–	–	–	–
			13							
			14	–	–	–	–	–	–	–
			15	–	–	–	–	–	–	–
			16							
			17							
			18	1	1	1	1	1	1	1
			19	1	–	–	–	–	–	–
			20	4	–	–	–	–	–	–
			21	2	–	–	–	–	–	–
			22	3	–	–	–	–	–	–
			23	3	2	2	2	2	2	2
			24	19	12	10	10	10	10	10
			25							
			26	7	–	–	–	–	–	–
			27	4	4	4	4	4	4	4
			28	10	3	1	1	1	1	1
			29	–	–	–	–	–	–	–
NOTES:				77	33	27	24	26	22	24
			G. Total	2091	1110	576	471	443	274	479

10-cell unit	No. of habitats	No. of habitats with water	No. habitats with Anopheles early	No. of habitats with Anopheles late	No. of habitats with Culex early	No. of habitats with Culex late	No. of habitats with pupae
30	2	2	2	2	2	2	2
31	–	–	–	–	–	–	–
32	3	3	3	3	3	3	3
33	7	5	5	5	5	5	5
34	4	1	1	1	1	1	1
35	–	–	–	–	–	–	–
36	7	7	7	7	7	7	7
37	9	8	8	8	8	8	8
38	60	18	18	18	18	18	18
39	–	–	–	–	–	–	–
40	8	6	6	6	6	6	6
41	14	12	11	6	8	2	6
42	6	–	–	–	–	–	–
43	–	–	–	–	–	–	–
44	14	14	2	2	2	2	2
45 H							
46	4	1	1	–	1	–	–
47	3	3	1	1	1	1	1
48	8	–	–	–	–	–	–
49							
50	–	–	–	–	–	–	–
51							
52	–	–	–	–	–	–	–
53							
54	–	–	–	–	–	–	–
55	3	–	–	–	–	–	–
56							
57	7	–	–	–	–	–	–
58	–	–	–	–	–	–	–
	159	80	65	59	62	55	59

Figure 6.5: Example of a completed weekly ward summary form

Summary form filled out by the Ward Supervisor and totalled along the bottom with a pocket calculator to enable rapid entry into monthly report templates at the municipal level.

All the Larval Surveillance CORPs' forms are collated in order of their TCU numbers in pre-labelled folders with the ward supervisor's summary sheet on top of the cluster of TCUs it summarizes. These folders are provided to the Municipal Mosquito Control Coordinator (MMCC) each week. The MMCC or the MMCIs directly under his/her supervision then checks that all forms have been filled out and submitted correctly, recording the results of this quality control exercise in a checklist designed for that purpose. The totals for each neighbourhood in this checklist, at the bottom of each ward supervisor's summary form (Figure 6.5), are then entered into a password protected excel spreadsheet template, tailored to each municipality. This template automatically generates summary statistics, tables and charts (Figure 6.6 and Figure 6.7) that form the backbone of the MMCCs monthly report to the City Mosquito Control Coordinator (CMCC). More importantly, the MMCC is responsible for identifying and reacting to signs of programme failure in the content of these forms within a week of their occurrence, documenting any actions taken in writing on those forms. These standard, automatically generated tables and charts are supplemented with written narratives summarizing successes, failures and responses to these monthly observations, as well as plans and requests for support to implement further action. A crucial part of the MMCCs duties is to coordinate, assess and execute corrective action in relation to the observations of his/her inspectors when conducting random spot checks to assure the quality of data reported by larval surveillance CORPs (Figure 6.4). The results of these quality control assessments by the MMCIs are also entered into the municipal monthly report template for examination by the CMCC and his/her two City Mosquito Surveillance Officers (CMSOs). The MMCC also receives a summary of the adult mosquito surveillance data for that week directly from the city-level Adult Mosquito Surveillance Supervisors so that this independent and more direct assessment of programme impact can be used to rigorously triangulate and interpret the larval surveillance data. This data are also included in the monthly municipal report with a preformatted component of the spreadsheet which automatically generates summary statistics and charts.

The City Mosquito Control Coordinator (CMCC) expects to receive the previous month's municipal reports in the first week of each month and is expected to provide verbal feedback, as well as annotated comments, on these reports in a meeting with the CMSOs, MMCCs and MMCIs to be held on or before the end of the second week of the month. The CMCC collates these data and adds them to existing records to generate a series of trend graphs and summary statistics that quantify and illustrate the progress of the programme in terms of impact on larval (Figure 6.8 and Figure 6.9) and adult-stage mosquitoes (Figure 6.10). By the start of 2007, the CMCC had begun presenting these reports at bimonthly coordination meetings with the partners of the primary donor for the programme at that time (US President's Malaria Initiative of the United States Agency for International Development).

A

Municipal larval survey- Monthly summary report Month: 12 Year: 2005 Ilala

Mtaa/Tawi	Folder	10-cell units	Total habitats					Wet habitats					Habitats with early instar Anopheles					Habitats with late instar Anopheles					Habitats with early instar Culicines					Habitats with late instar Culex					Habitats with Pupae				
Week:			1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
BUGURUNI WARD																																					
Mnyamani	1	82	885	891	898	891	0	410	397	377	356	0	11	11	11	7	0	11	11	11	8	0	230	305	243	221	0	220	291	224	214	0	218	279	221	194	0
Malapa	2	66	183	194	194	194	0	73	81	117	81	0	24	25	26	35	0	25	27	26	36	0	47	49	53	57	0	47	49	53	57	0	46	48	54	56	0
Madenge	3	49	182	176	176	176	0	17	19	18	18	0	0	1	4	4	0	2	5	4	4	0	5	7	16	16	0	15	16	16	16	0	15	16	15	15	0
Kisiwani	4	91	220	150	200	334	0	230	147	182	302	0	133	5	7	17	0	130	5	7	13	0	156	59	71	144	0	145	51	87	150	0	103	28	38	98	0
TOTALS:		288	1470	1411	1468	1595	0	730	644	694	757	0	168	42	48	63	0	168	48	48	61	0	438	420	383	438	0	427	407	380	437	0	382	371	328	363	0
PROPORTION OF WET HABITATS OCCUPIED:													0.230	0.058	0.066	0.086	0.000	0.230	0.066	0.066	0.084	0.000	0.600	0.575	0.525	0.600	0.000	0.585	0.558	0.521	0.599	0.000	0.523	0.508	0.449	0.497	0.000
ILALA WARD																																					
Sharif Shamba	5	43	223	219	233	231	0	108	111	113	116	0	37	33	28	32	0	14	13	14	13	0	88	94	86	83	0	88	94	86	83	0	11	19	18	15	0
Mafuriko	6	35	204	230	230	481	0	85	99	109	229	0	6	4	1	93	0	6	4	1	1	0	60	74	71	9	0	76	74	71	68	0	74	69	69	65	0
Karume	7	33	57	58	67	78	0	8	9	14	26	0	2	5	3	4	0	2	5	3	4	0	7	7	3	9	0	7	7	3	9	0	6	7	3	9	0
Kasulu	8	39	126	129	131	131	0	47	43	52	50	0	0	0	0	0	0	0	0	0	0	0	29	18	27	27	0	29	18	27	27	0	29	18	26	23	0
TOTALS:		150	610	636	661	921	0	248	262	288	421	0	45	42	32	129	0	22	22	18	18	0	184	193	187	128	0	200	193	187	187	0	120	113	116	112	0
PROPORTION OF WET HABITATS OCCUPIED:													0.181	0.169	0.129	0.520	0.000	0.089	0.089	0.073	0.073	0.000	0.742	0.778	0.754	0.516	0.000	0.806	0.778	0.754	0.754	0.000	0.484	0.456	0.468	0.452	0.000
KIPAWA WARD:																																					
Kipawa	9	57	382	383	381	382	0	204	198	178	183	0	72	67	55	60	0	56	47	41	45	0	88	94	78	84	0	78	74	65	65	0	60	44	47	47	0
Karakata	10	55	1147	1215	776	1019	0	586	615	339	585	0	104	125	63	94	0	83	101	44	28	0	188	211	73	174	0	103	128	67	37	0	78	82	49	41	0
Mogo	11	63	806	893	949	928	0	338	337	333	335	0	162	173	192	172	0	93	108	110	97	0	159	173	186	169	0	143	137	138	115	0	95	75	93	83	0
Kipunguni	12	47	568	590	590	570	0	416	414	391	387	0	226	178	192	207	0	218	160	182	202	0	227	229	212	241	0	223	209	194	216	0	209	153	170	190	0
TOTALS:		222	2903	3081	2696	2899	0	1544	1564	1241	1490	0	564	543	502	533	0	450	416	377	372	0	662	707	549	668	0	547	548	464	433	0	442	354	359	361	0
PROPORTION OF WET HABITATS OCCUPIED:													0.365	0.352	0.325	0.345	0.000	0.291	0.269	0.244	0.241	0.000	0.429	0.458	0.356	0.433	0.000	0.354	0.355	0.301	0.280	0.000	0.286	0.229	0.233	0.234	0.000
MCHIKICHINI WARD:																																					
Ilala Kota	13	68	434	428	447	443	0	383	371	377	378	0	55	50	49	46	0	56	50	49	40	0	158	148	132	126	0	157	147	132	126	0	95	69	61	32	0
Mission Kota	14	29	117	118	117	117	0	96	94	92	86	0	6	3	2	1	0	6	3	2	1	0	69	62	59	49	0	69	62	59	49	0	69	62	59	45	0
Msimbazi Bondeni	15	68	796	809	810	820	0	538	544	541	529	0	88	69	46	40	0	88	69	47	40	0	435	406	362	358	0	434	406	362	358	0	97	24	7	4	0
TOTALS:		165	1347	1355	1374	1380	0	1017	1009	1010	993	0	149	122	97	87	0	150	122	98	81	0	662	616	553	533	0	660	615	553	533	0	261	155	127	81	0
PROPORTION OF WET HABITATS OCCUPIED:													0.147	0.120	0.095	0.086	0.000	0.147	0.120	0.096	0.080	0.000	0.651	0.606	0.544	0.524	0.000	0.649	0.605	0.544	0.524	0.000	0.257	0.152	0.125	0.080	0.000
VINGUNGUTI WARD:																																					
Mtakuja	16	75	324	326	329	352	0	96	85	74	103	0	6	5	5	9	0	4	5	5	6	0	21	26	32	46	0	20	24	30	32	0	19	24	30	32	0
Miembeni	17	56	257	267	271	277	0	109	110	102	88	0	9	10	10	8	0	17	15	8	7	0	17	24	24	22	0	35	29	23	22	0	36	29	23	23	0
Kombo	18	97	430	442	443	462	0	161	151	124	140	0	60	41	27	35	0	48	28	9	12	0	68	52	35	34	0	63	45	29	22	0	60	35	20	20	0
Mtambani	19 & 20	103	453	469	476	492	0	231	222	224	223	0	13	17	7	9	0	13	18	7	9	0	31	29	29	28	0	31	29	27	28	0	33	35	36	32	0
TOTALS:		331	1464	1504	1519	1583	0	597	568	524	554	0	88	73	49	61	0	82	66	29	34	0	137	131	120	130	0	149	127	109	104	0	148	123	109	107	0
PROPORTION OF WET HABITATS OCCUPIED:													0.147	0.122	0.082	0.102	0.000	0.137	0.111	0.049	0.057	0.000	0.229	0.219	0.201	0.218	0.000	0.250	0.213	0.183	0.174	0.000	0.248	0.206	0.183	0.179	0.000
OVERALL TOTALS		1156	7794	7987	7718	8378	0	4136	4047	3757	4215	0	1014	822	728	873	0	872	674	570	566	0	2083	2067	1792	1897	0	1983	1890	1693	1694	0	1353	1116	1039	1024	0
OVERALL PROPORTIONS OF WET HABITATS OCCUPIED													0.245	0.203	0.194	0.207	#####	0.211	0.167	0.152	0.134	#####	0.504	0.511	0.477	0.450	#####	0.479	0.467	0.451	0.402	#####	0.327	0.276	0.277	0.243	#####

BUGURUNI WARD

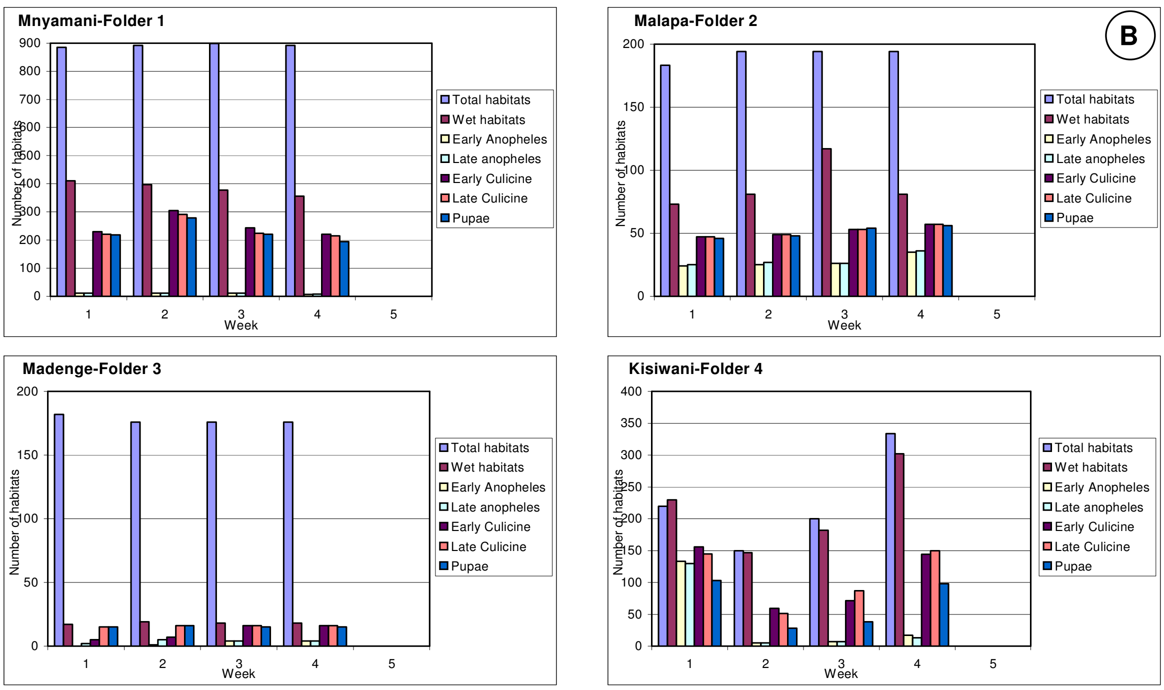


Figure 6.6: Example of a mosquito larval surveillance component in a municipal monthly report template

A. The overall data entry table in which each row corresponds to one, or occasionally two (see bottom row for example of a very large neighbourhood) folders, each containing 4 or 5 sequential weekly ward summary forms and respective sets of CORPs larval surveillance forms. Note that weeks overlapping two months are assigned to specific calendar months in advance so that each operational month has a predefined start and end date, spanning exactly 4 or 5 weeks. B. A typical automatically generated chart summarizing the observed distribution of larval habitat abundance and mosquito occupancy in one ward.

Adult mosquito survey summary Month: April Year: 2006 Ilala **A**

Mtaa/Tawi	An gambiae					An funestus					Other Anopheles					Culex					Aedes					Mansonia					Others				
Week (Site)	1	2	3	4	Avg	1	2	3	4	Avg	1	2	3	4	Avg	1	2	3	4	Avg	1	2	3	4	Avg	1	2	3	4	Avg	1	2	3	4	Avg
BUGURUNI WARD																																			
Mnyamani	0	0	0	0	0.0	0	0	0	1	0.3	0	0	0	0	0.0	56	0	68	42	41.5	0	0	0	0	0.0	0	0	0	0	0.0	0	0	0	0	0.0
Malapa	0	0	0	0	0.0	0	0	0	0	0.0	0	0	0	0	0.0	95	67	77	0	59.8	0	0	0	0	0.0	0	0	0	0	0.0	0	0	0	0	0.0
Madenge	0	0	1	0	0.3	0	0	0	0	0.0	0	0	0	0	0.0	0	81	38	29	37.0	0	0	0	0	0.0	0	0	0	0	0.0	0	0	0	0	0.0
Kisiwani	0	0	1	1	0.5	0	0	0	0	0.0	0	0	0	0	0.0	0	0	50	61	27.8	0	0	0	0	0.0	0	0	0	0	0.0	0	0	0	0	0.0
AVERAGES:	0.0	0.0	0.5	0.3	0.2	0.0	0.0	0.0	0.3	0.1	0.0	0.0	0.0	0.0	0.0	37.8	37.0	58.3	33.0	41.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTALS:	0	0	2	1	3	0	0	0	1	1	0	0	0	0	0	151	148	233	132	664	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ILALA WARD																																			
Sharif Shamba	0		5	0	1.7	0		0	0	0.0	0		0	0	0.0	0		344	387	###	0		0	0	0.0	0		0	0	0.0	0		0	0	0.0
Mafuriko	0		2	1	1.0	0		0	0	0.0	0		0	0	0.0	0		32	28	20.0	0		0	0	0.0	0		0	0	0.0	0		0	0	0.0
Karume	1		0	0	0.3	0		0	0	0.0	0		0	0	0.0	26		40	33	33.0	0		0	0	0.0	0		0	0	0.0	0		0	0	0.0
Kasulu	0		2	0	0.7	0		0	0	0.0	0		0	0	0.0	0		48	114	54.0	0		0	0	0.0	0		0	0	0.0	0			0	0.0
AVERAGES:	0.3		2.3	0.3	0.9	0.0		0.0	0.0	0.0	0.0		0.0	0.0	0.0	6.5		116.0	140.5	87.7	0.0		0.0	0.0	0.0	0.0		0.0	0.0	0.0	0.0		0.0	0.0	0.0
TOTALS:	1		9	1	11	0		0	0	0	0		0	0	0	26		464	562	1052	0		0	0	0	0		0	0	0	0		0	0	0
KIPAWA WARD:																																			
Kipawa	0	0	3		1.0	0	0	0		0.0	0	0	0		0.0	0	0	133		44.3	0	0	0		0.0	0	0	0		0.0	0	0	0		0.0
Karakata	6	0	1		2.3	0	0	0		0.0	0	0	0		0.0	55	68	61		61.3	0	0	0		0.0	0	0	0		0.0	0	0	0		0.0
Mogo	1	1	0		0.7	0	0	0		0.0	0	0	0		0.0	0	57	67		41.3	0	1	0		0.3	104	0	0		34.7	0	0	0		0.0
Kipunguni	3	0	10		4.3	0	0	0		0.0	0	0	0		0.0	0	61	102		54.3	40	0	4		14.7	0	0	0		0.0	0	0	0		0.0
AVERAGES:	2.5	0.3	3.5		2.1	0.0	0.0	0.0		0.0	0.0	0.0	0.0		0.0	13.8	46.5	90.8		50.3	10.0	0.3	1.0		3.8	26.0	0.0	0.0		8.7	0.0	0.0	0.0		0.0
TOTALS:	10	1	14		25	0	0	0		0	0	0	0		0	55	186	363		604	40	1	4		45	104	0	0		104	0	0	0		0
MCHIKICHINI WARD:																																			
Ilala Kota	6	16	4		8.7	0	0	0		0.0	0	10	7		5.7	64	432	183		###	0	0	0		0.0	2	0	0		0.7	3	0	0		1.0
Mission Kota	7	3	3		4.3	0	0	0		0.0	0	0	0		0.0	89	140	75		101.3	1	0	0		0.3	0	0	0		0.0	0	0	0		0.0
Msimbazi Bondeni	21	0	12		11.0	0	0	0		0.0	0	0	2		0.7	26	0	39		21.7	0	0	0		0.0	0	0	0		0.0	0	0	0		0.0
AVERAGES:	11.3	6.3	6.3		8.0	0.0	0.0	0.0		0.0	0.0	3.3	3.0		2.1	59.7	190.7	99.0		116.4	0.3	0.0	0.0		0.1	0.7	0.0	0.0		0.2	1.0	0.0	0.0		0.3
TOTALS:	34	19	19		72	0	0	0		0	0	10	9		19	179	572	297		1048	1	0	0		1	2	0	0		2	3	0	0		3
VINGUNGUTI WARD:																																			
Mtakuja	0		6		3.0	0		0		0.0	0		0		0.0	138		152		145.0	0		0		0.0	0		0		0.0	0		0		0.0
Miembeni	0		2		1.0	0		0		0.0	0		0		0.0	220		127		173.5	0		0		0.0	0		0		0.0	0		0		0.0
Kombo	6		0		3.0	0		0		0.0	0		0		0.0	34		63		48.5	0		0		0.0	0		0		0.0	0		0		0.0
Mtambani	0		13		6.5	0		0		0.0	0		0		0.0	0		279		139.5	0		0		0.0	0		0		0.0	0		0		0.0
AVERAGES:	1.5		5.3		3.4	0.0		0.0		0.0	0.0		0.0		0.0	98.0		155.3		126.6	0.0		0.0		0.0	0.0		0.0		0.0	0.0		0.0		0.0
TOTALS:	6	0	21		27	0		0		0	0		0		0	392		621		1013	0		0		0	0		0		0	0		0		0
OVERALL AVERAGES:	3.1	1.3	3.6	0.1	2.9	0.0	0.0	0.0	0.1	0.0	0.0	0.7	0.6	0.0	0.4	43.1	54.8	103.9	34.7	84.5	2.1	0.1	0.2	0.0	0.8	5.3	0.0	0.0	0.0	1.8	0.2	0.0	0.0	0.0	0.1
OVERALL TOTALS:	51	20	65	2	138	0	0	0	1	1	0	10	9	0	19	803	906	1978	694	4381	41	1	4	0	46	106	0	0	0	106	3	0	0	0	3

Ilala Ward

B

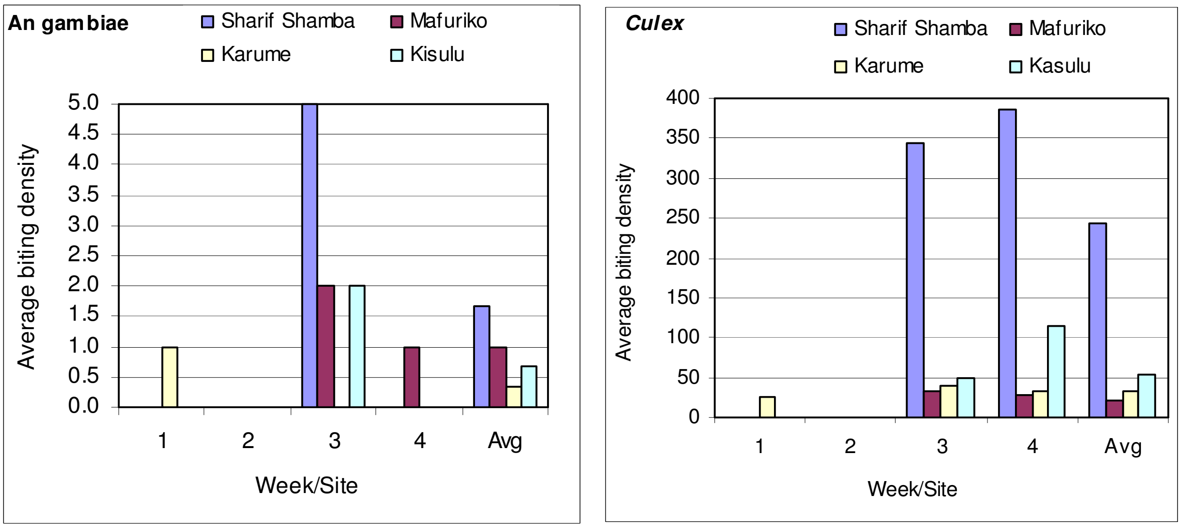


Figure 6.7: Example of a mosquito adult surveillance component in a municipal monthly report template

A. The overall data entry table (empty fields indicate missing data) B. A typical automatically generated chart summarizing the observed distribution of adult mosquitoes.

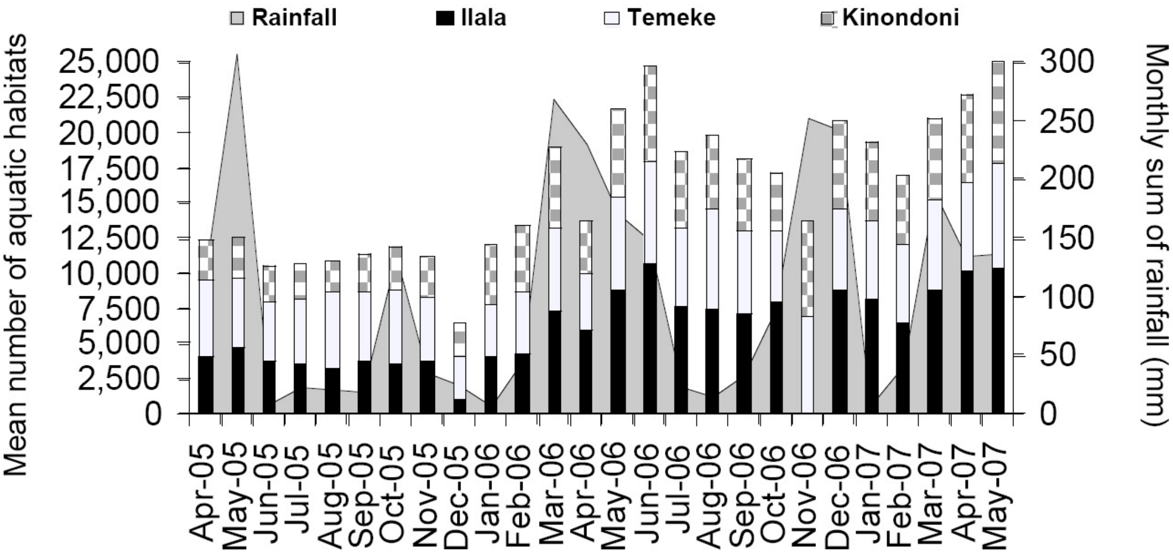


Figure 6.8: Monthly average of aquatic habitats surveyed in the three municipalities Kinondoni, Ilala and Temeke from February 2005 to March 2007 in relation to rainfall

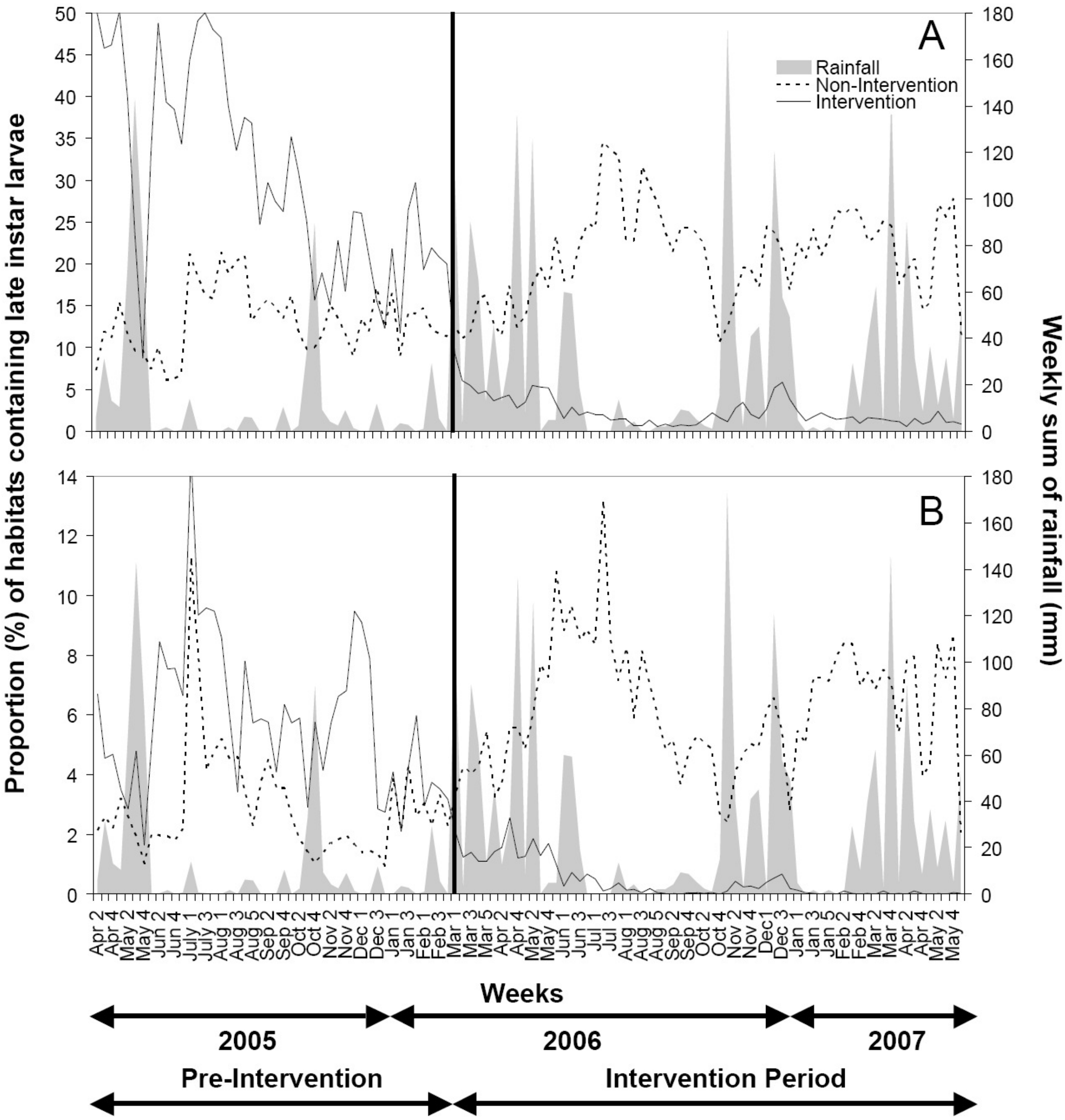


Figure 6.9: **Impact of seasonal rainfall variation and larvicide application on aquatic-stage mosquito populations between April 2005 and June 2007**

Larvicide application started in the intervention sites in March 2006 week number 1. A: Proportion of aquatic habitats containing late instar culicine larvae at weekly surveys. B: Proportion of aquatic habitats containing late instar anopheline larvae at weekly surveys.

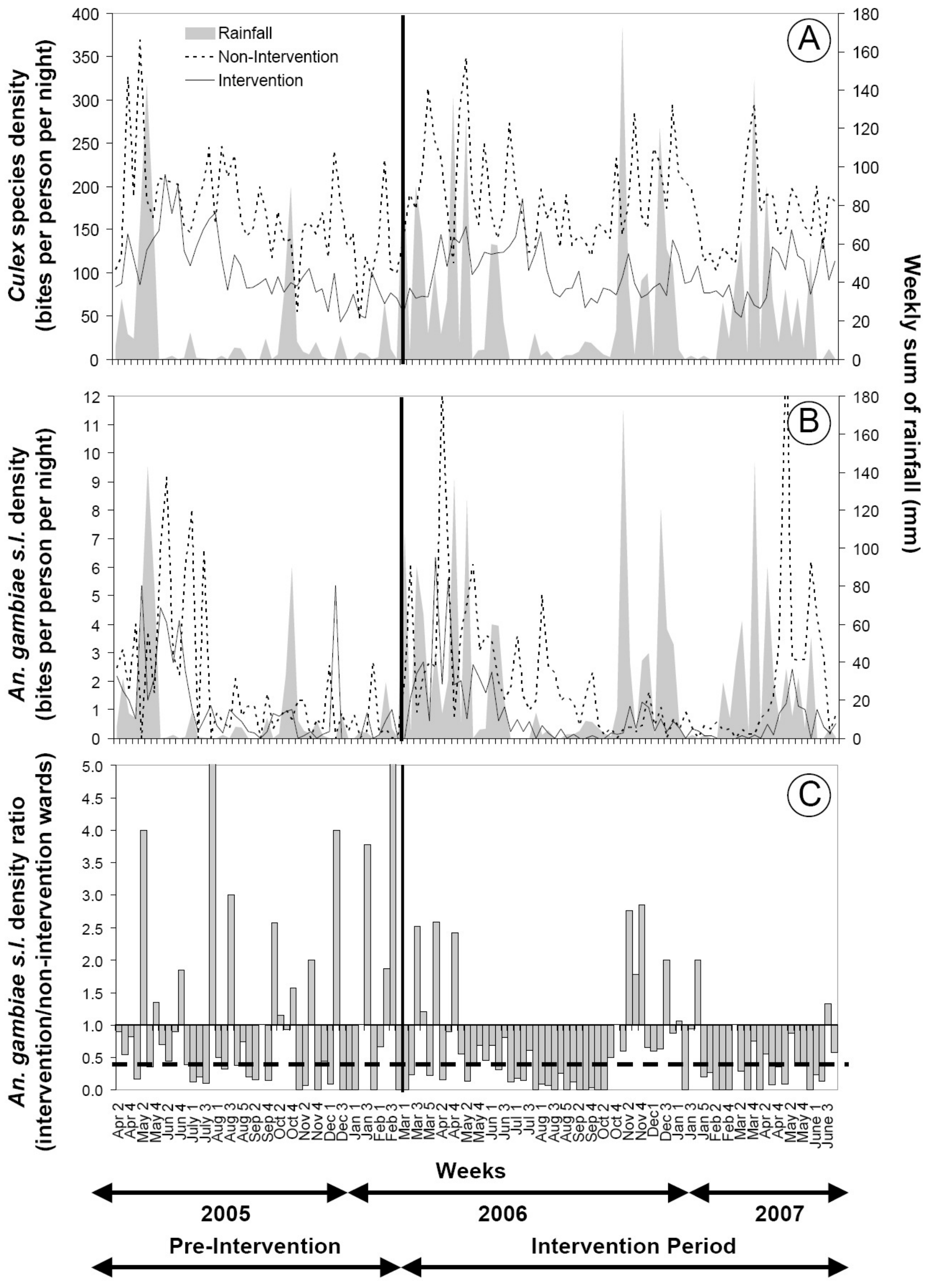


Figure 6.10: Impact of seasonal rainfall variation and larvicide application on weekly adult mosquito densities between April 2005 and June 2007

A. Rainfall and densities of adult *Culex* species, B. Rainfall and densities of adult *Anopheles gambiae s.l.*, C. The ratio of densities of *An. gambiae s.l.* in intervention wards relative to non-intervention wards. The line representing the x-axis in panel C represents equivalence of densities in intervention and *a priori* selected non-intervention wards while the vertical black line represents the initiation of larviciding activities. The thick, broken horizontal line in panel C represents the ratio of exposure estimated to be provided by an insecticide-treated net in urban Dar es Salaam (Geissbühler et al. 2007a).

Analyses

To describe changes in mosquito densities associated with larviciding the percentage reduction in mosquito densities in larviciding areas was calculated using an established formula (Fillinger et al. 2003, Majambere et al. 2007, Mulla et al. 1971) which takes into account that natural changes (for instance through predation or changes in climatic conditions) in the mosquito populations are taking place over time at the same level and rate in both treated (intervention) and untreated (non-intervention) sites. Therefore, the percentage reduction is defined as follows:

$$\% \text{ reduction} = 100 - (C_1/T_1 \times T_2/C_2) \times 100$$

where C_1 and C_2 describe the average density of mosquitoes in untreated (non-intervention) sites during baseline and intervention periods, and T_1 and T_2 describe the average density of mosquitoes in intervention sites during baseline (when no larviciding took place yet) and intervention periods (when larvicides were applied weekly) (Mulla et al. 1971). All figures presented as “percentage reduction” throughout the paper have been calculated using this formula.

All measured adult mosquito biting densities were multiplied by 1/0.75 to get biting rates for a full hour (Geissbühler et al. 2007a). Generalized estimating equations (GEE) were run with SPSS 15.0 to calculate differences in mosquito biting rates and EIR between intervention and non-intervention areas with ten-cell units as a subject unit, log linked mosquito densities and intervention and non-intervention areas as the factor (Table 6.4). In order to adjust for total exposure indoors and outdoors, outdoor mosquito densities were multiplied by the ratio of the total true human exposure (the sum of the hourly mean of the indoor and outdoor biting rates, weighted according the proportion of time human beings typically spend in these two compartments) divided by the total outdoor biting rate as estimated previously (Geissbühler et al. 2007a). These ratios were derived from an in depth mosquito survey which was conducted during the main rainy season in 2006 (*An. gambiae*: 0.67, *An. funestus*: 0.725, *Anopheles coustani*: 0.448 and *Culex*: 0.94) (Geissbühler et al. 2007a).

Table 6.4: Comparison of mean human biting rates (HBR) of *An. gambiae s.l.* and *Culex sp.* and entomological inoculation rate (EIR) for *An. gambiae s.l.* in the intervention and non-intervention wards during baseline and first year of intervention. 95% confidence intervals in parenthesis.

	Pre-Intervention [a]			First intervention year [b]			
	Non-Intervention Wards	Intervention Wards	*p* [c]	Non-Intervention Wards	Intervention Wards	*p*	Percentage Reduction
Annual mean							
Daily HBR *An. gambiae*	0.93 (0.60-1.46)	0.72 (0.51-1.02)	0.367	0.94 (0.57-1.56)	0.50 (0.38-0.68)	0.040	31.3%
Annual EIR *An. gambiae*	1.05 (0.68-1.65)	0.81 (0.58-1.15)		1.06 (0.64-1.77)	0.56 (0.43-0.77)		
Daily HBR *Culex sp.*	173.9 (140.7-214.9)	86.8 (72.7-103.7)	<0.001	171.5 (137.2-214.3)	86.1 (70.9-104.4)	<0.001	0%
Dry season mean (July-August-September)							
Daily HBR *An. gambiae*	0.59 (0.32-1.11)	0.46 (0.29-0.72)	0.505	1.17 (0.56-2.47)	0.12 (0.08-0.20)	<0.001	86.8%
EIR *An. gambiae*	0.67 (0.36-1.26)	0.52 (0.33-0.81)		1.32 (0.63-2.79)	0.14 (0.09-0.22)		
Daily HBR *Culex sp.*	196.3 (157.9-244.0)	98.4 (82.2-117.9)	<0.001	151.1 (125.3-192.0)	86.1 (67.1-110.6)	<0.001	0%

[a] April 2005 – March 2006; March 2006 has been included in the calculation for the baseline year since reductions of adult mosquitoes due to larviciding cannot be expected earlier than 3-4 weeks into the intervention (Fillinger & Lindsay 2006).
[b] April 2006 – March 2007.
[c] Generalized estimating equations (GEE) were used to analyse pre-intervention data and data from the first year of intervention, respectively. In each analyses mean densities are compared between non-intervention and intervention sites. Ten-cell units were used as a subject unit, log linked mosquito densities and intervention and non-intervention areas as the factor.

Ethics

All participants provided informed consent. No persons in high risk groups, namely people under 18 years or women of reproductive age, were recruited to conduct human landing catches. Furthermore, the catchers are screened every week for malaria by microscopic examination of thick smear peripheral blood samples and treated with artemisinin-based combination therapy when diagnosis was positive. Research clearance was obtained from the Medical Research Coordination Committee of the National Institute of Medical Research in Tanzania (NIMR/HQ/R.8a/Vol. IX/279) the Tanzanian Commission of Science and Technology (No. 2004-69-MFS-2004-24) and Durham University's Ethics Advisory Committee (No. 03 EAC R131).

6.4 Results

Overall, the vector surveillance and management systems developed in Dar es Salaam allowed timely collection, interpretation and reaction to field-collected entomologic data with reaction times at ward, municipal and city levels of one day, week and month, respectively. In fact, the vector density patterns as presented in Figure 6.9 and Figure 6.10 were drafted into manuscript format figures within three weeks of their collection through these standard low-technology procedures, therefore serving as an instant monitoring and teaching tool. In contrast, more complex, research driven analyses (Table 6.4), which require elaborate data entry procedures, can only be achieved with several months delay.

The implementation of the programme through local community-based staff led to high community acceptance and support. The procedures and staff management systems described, greatly improved standards of larval surveillance relative to that reported at the outset of this programme (Vanek et al. 2006). Vanek and others (2006) reported that only 42% of potential *Anopheles* habitats were detected by CORPs prior to the introduction of the programme management systems described here. By the end of 2005, the independent spot checks of the Municipal Mosquito Control Inspectors revealed that all three municipalities had larval surveillance coverage levels exceeding 75% (Figure 6.11). Based on this result the decision was taken to implement larviciding in three selected wards since substantial reductions of malaria exposure and burden for resident populations (Gu & Novak 2005, Gu & Novak 2006, Killeen et al. 2006b) were expected if such coverage levels could be approached with actual larvicidal control.

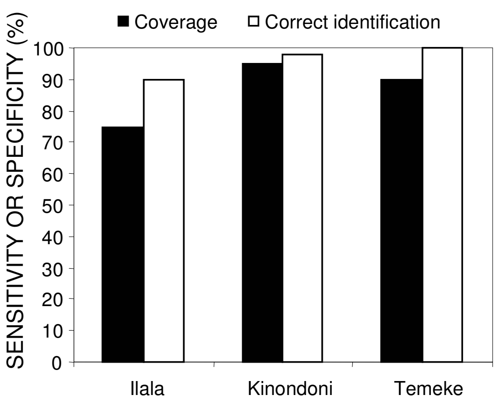


Figure 6.11: Proportion of habitats successfully detected (sensitivity) and correctly identified (specificity) by larval surveillance CORPs in November 2005

Determined from the random on-site spot checks of the Municipal Mosquito Control Inspectors using methodology essentially identical to earlier evaluations of larval surveillance (Vanek et al. 2006).

Larviciding began in three wards in the first week of March 2006 (Figure 6.1). By that time more than 65,000 potential *Anopheles* habitats spread out over a 55 km^2 area occupied by more than 612,000 people were surveyed on a weekly basis. At any sampling date, between 10 and 50% of all habitats contained water (Figure 6.8).

The first year of larviciding successfully reduced the number of larval habitats (Figure 6.9). In the three non-intervention wards the proportion of habitats that contained late instar anopheline and culicine larvae increased from March 2006 onwards by an average of 53% and 37%, respectively, as compared to the baseline year. This is probably associated with more rainfall in 2006 (1526 mm) compared to 2005 (979 mm) leading to an increase in fresh water and suitable habitats (Figure 6.8). In marked contrast, the number of habitats with anophelines and culicines both fell in average by over 90% in the three intervention wards as compared to the baseline year. Overall percentage reduction in *Anopheles* larval habitat abundance was 96.5% assuming that without larviciding larval populations would have risen by the same rate as in non-intervention wards (Mulla et al. 1971).

The vast majority of 245,927 adult mosquitoes collected in the year before intervention were culicines represented by *Culex* sp. (97.7 %), *Mansonia* sp. (0.9%) and *Aedes* sp. (0.4 %). Only 1% (2,468) of these were anophelines. *An. gambiae s.l.* represented 76.6% (1,864) of the anophelines and was by far the most common vector. Only a small number of *An. funestus* (85; 3.5%) were identified through the adult surveillance system. Laboratory analyses confirmed transmission by both *An. gambiae s.l.* and *An. funestus* with sporozoite rates of 0.31% and 1.25% (Geissbühler et al. 2007b, submitted), respectively. A sub-sample of 1,099 members of the *An. gambiae* species complex were identified as 75.6% *An. gambiae s.s.*, 21.3% *An. arabiensis* and 3.1% *An. merus*.

Culicine mosquitoes were abundant in all study wards and showed little seasonality throughout the year (Figure 6.10A). During the baseline data collection the average culicine human biting rate was nearly twice as high in the wards chosen *a priori* as controls for the intervention and this proportion did not change during the intervention (Table 6.4) indicating that routine larvicide application did not suppress the nuisance biting rate.

Adult densities of the primary vector, *An. gambiae s.l.*, were highly seasonal (Figure 6.10B). Although the mean *An. gambiae s.l.* human biting rate and annual EIR was higher in the control wards than the intervention wards during the baseline year, this difference was not significant (Table 6.4). In contrast, in the first 12 months of intervention, the mean human biting rate and annual EIR remained approximately the same in the non-intervention wards (Table 6.4) but decreased by one third in wards where larval control was implemented following the general trend observed in the larval surveys. The difference in transmission intensity between non-intervention and intervention wards was significant (p=0.04) in the first year of larval control (Table 6.4) even though an overall percentage reduction of 31.3% might appear modest compared to the impact shown on larval habitat abundance. Notably, the dry season larviciding in July-August-September 2006 led to a percentage reduction in transmission by 87% when compared with the same time period pre-intervention and non-intervention sites. In marked contrast to the pre-intervention year, weekly mean adult mosquito densities in intervention areas were constantly lower than those in non-intervention areas for six consecutive months from May to October 2006, and for five consecutive months from mid January to mid June 2007 (Figure 6.10C). However, little to no effect was achieved during the primary (March-June) and secondary (October-December) rainy seasons in 2006 (Figure 6.10B). Larviciding was only begun with the onset of the main rains of 2006 and it took several weeks for programme staff to refine their performance based on hands-on experience. Although the proportion of habitats containing late instar larvae decreased from the start of larviciding, it is important to note that the actual numbers of habitats available increased substantially in March 2006 (Figure 6.8), resulting in significant larval development and possibly emergence. Thus, although adult *An. gambiae s.l.* densities in intervention wards steadily dropped till the end of September 2006 (Figure 6.10), the introduction of the intervention came too late to prevent the bulk of transmission resulting from the main rains from March to May 2006.

An additional challenge confronted the programme staff during the short rains at the end of 2006. Simultaneous rains and municipal maintenance of waste water settlement ponds in each of the intervention wards generated substantial areas of inaccessible larval habitats ideal for *An. gambiae s.l.* on the surface of freshly drained mud flats (Figure 6.12). Crucially, these three water treatment facilities were located within 100 meters of at least one adult mosquito surveillance site each so their influence upon recorded *An. gambiae s.l.* densities was substantial. Once these ponds had been fully renovated and these areas either dried out or were filled up, malaria vector densities were once again successfully controlled. Nevertheless, because of programme limitations during both seasonal rainfall peaks in 2006, the overall impact on malaria transmission for the first intervention year was very modest. Preliminary results from the main rains (April-June) in 2007 (Figure 6.10) though indicate an improvement in the operational procedures which led to a percentage reduction of transmission by 71% as compared to the same time period at baseline and by 62% as compared to the start of the intervention in 2006.

6.5 Discussion

After only one year of operational larviciding in Dar es Salaam a clear impact of the intervention on malaria vectors was demonstrated. Overall anopheline larval abundance was reduced by 96% in the intervention wards compared to historical and contemporary controls which consequently resulted in a significant reduction of 31% of malaria transmission by *An. gambiae s.l.*. Furthermore, preliminary analyses of parasitological surveys (Y. Geissbühler and M.C. De Castro, personal communication).showed that the larviciding was associated with an overall reduction of 40% ($p<0.001$) of *P. falciparum* infection prevalence in the study population and that highest impact was achieved during the dry season of 2006. Interestingly, the majority of infected mosquitoes in Dar es Salaam were found during the dry seasons which also coincided with maximum larval control success (Y. Geissbühler, personal communication).

The control of nuisance mosquitoes remained unsatisfactory. Similar to observations in other urban centres in East Africa, where anti-larval measures for malaria control were implemented (Lindsay et al. 2004), the overall culicine densities remained high in the intervention wards which might be explained by the large number of closed habitats like pit latrines, soakage pits, septic tanks and water storage tanks, which were not included in the weekly larvicide applications. The three-month cycle for interventions targeted at closed habitats is probably too long to suppress larval development in these often highly polluted breeding sites. Furthermore, no rigorous system existed for monitoring coverage of these habitats, to which access is often difficult or not possible at all. While targeting the interventions at *Anopheles* breeding sites makes economic sense, it may not be practicable. Culicine mosquitoes are responsible for over 100 bites per exposed person per night in Dar es Salaam. Targeting *Anopheles* habitats only would most likely lead to the withdrawal of the communities' support as has been shown in the past (Bang et al. 1977, Chavasse et al. 1996, Stephens et al. 1995).

Figure 6.12: Examples of inaccessible but productive *Anopheles* aquatic habitats in the wards of Buguruni (A), Mikocheni (B) and Kurasini (C) during the period October to December 2006

Note that all the open soil surfaces depicted are in fact very soft mud which is impossible to walk across. Although these ponds had been freshly drained for maintenance, their low porosity, and the rainfall which immediately followed their exposure, resulted in abundant and stable surface water in multiple inaccessible depressions on the surface for two months. These areas closely resemble similarly challenging sites in flooding river valleys of West Africa which can be rigorously controlled with powered granule-blowing equipment (Majambere et al. 2007).

Nevertheless, *Culex* control appears not worth doing unless the numbers can be reduced sufficiently to convince inhabitants that larval control, in general, is a good idea. Therefore, new strategies including the implementation of environmental modifications need to be urgently developed to address the nuisance biting problem in Dar es Salaam.

The UMCP's unique feature is the surveillance and management system described here which proved to be practical and affordable (Worrall 2007) and allowed operational response times to changing ecological and programmatic conditions that were previously unthinkable at this scale. The strong involvement of community-based staff, local capacity building, direct governmental participation and commitment in all phases of the programme, data-driven decision making and hands-on technical and programmatic support from national and international partners constitute a strong basis for future sustainability of control activities and have been pointed out to be important factors for success in malaria control programmes (Barat 2006, Impoinvil et al. 2007, Walker & Lynch 2007).

Despite the overall encouraging impact on malaria transmission, the wet season results in 2006 were clearly unsatisfactory. Nevertheless, it needs to be cautioned that adult mosquito sampling was most likely somewhat biased towards overestimating the contribution of the settlement ponds illustrated in Figure 6.12. Furthermore, detailed spatial analyses of the data need to be carried out to investigate the possibility of immigration of adult mosquitoes from non-treated areas outside the relatively small intervention wards. This might have contributed to the overall modest difference in adult densities between control and intervention wards which stands in sharp contrast to the observations of larval abundance. It is noteworthy, however, that the levels of suppression achieved before and after the short rains in late 2006 comfortably exceeded recent estimates (Geissbühler et al. 2007a) for the personal protection against exposure provided by an insecticide-treated net in this urban setting (Figure 6.10C).

To achieve effective control, larviciding programmes must clearly suppress transmission not only in the dry season when mosquitoes are most vulnerable but also when their numbers peak during and after the wet season. Both wet seasons in 2006 provided useful lessons and highlight the importance of long-term commitment for successful malaria control with larvicides in urban Africa. The first and most important wet season of 2006 illustrates the importance of being prepared for major transmission surges and the value of hands-on experience. Consistent with our observations of improving staff skills and performance, the impact of larviciding steadily increased following initiation, but the intervention was started too late for improving effectiveness to have a major impact on the intense peak of transmission in 2006.

Much of this can be attributed to the slow financing mechanisms for the programme at that time. All of the financial support for this programme was only secured in mid 2006, with limited interim pre-financing and insecticide donations provided in advance by the research partners at their own risk. These cash flow restrictions meant that equipment, supplies, personnel costs and training could not be assembled and coordinated before this key transmission season, so a vital opportunity to reduce malaria exposure was missed. For most of the programme's existence it has been necessarily pre-financed on an *ad hoc* (and therefore intermittent and unreliable) basis by its primary research partners, without which none of the data or methodologies presented would have been realized. The lack of sustainable funding has been identified as one of the major obstacles in the planning and implementation of mosquito control interventions in general (Barat 2006, Impoinvil et al. 2007, Kouznetsov 1977) and a recent evaluation of malaria control programmes in Eritrea, Brazil, India and Vietnam (Barat 2006) showed that sufficient and flexible financing, decentralized control of resources and local prioritisation of spending was key to success. As of March 2007, one of the research partners of the UMCP has instituted a risk-assessed pre-financing mechanism specifically to support smooth distribution of cash, equipment and supplies to the programme during the slow process of grant allocation and administration from donors. Such credit support from intermediary institutions is, however, likely to be the exception rather than the rule and stable funding mechanisms must be developed if larviciding programmes which rely on continuous weekly application cycles are to be stably implemented and supplied based on long-term development plans.

The unforeseen creation of major, inaccessible larval habitats during the short rainy season at the end of 2006 underlines the importance of experience and long-term commitment to programmes which rely so much on locally-specific tactical adaptation. While the need for powered granule blowers for occasionally difficult habitats (Majambere et al. 2007) is now obvious, this was not the case at the outset of this endeavour. With the scheduled scale-up of the interventions to nine wards from June 2007 and 15 wards from June 2008 further surprises are anticipated. Solutions to such challenges are likely to be found, however, the maturation of the programme's capacity to tackle the full range of such operational challenges will require at least additional 1-2 years of practical implementation experience.

It is necessary to point out that the UMCP is currently a combination of an operational programme, a research project and a training platform to provide the evidence and capacity needed for future programmes. Therefore, the activities implemented to date are very comprehensive and intensive. As the programme matures there should be opportunity to scale down some of these activities. For example, the mapping and recording of every plot could be simplified since for a solely operational programme not each individual water body needs to be characterised by an individual ID number. Furthermore, while weekly application of larvicides to all aquatic habitats remains necessary, the weekly larval surveillance (follow up) of every single habitat could be reduced to spot checks of a representative number of randomly selected habitats every week for monitoring and evaluation purposes. Nevertheless, it needs to be emphasized that such strategies should only be developed and fine-tuned over time as the program staff gains more experience. To monitor the disease impact of a vector control programme household and malaria surveys (Castro et al. 2007, submitted) need to be implemented. Nevertheless, these need not to be necessarily part of the vector control programme but should be implemented through national disease monitoring and evaluation procedures, preferably integrated in health information systems for core health and poverty indicators that serve local, national and global needs (de Savigny & Binka 2004).

6.6 Conclusions

A novel management system for implementing systematic larviciding of malaria vectors in African cities, that includes an intensive monitoring and evaluation component, has exhibited considerable potential for sustained, rapidly responsive, data-driven and affordable application. Despite operational and financial limitations in the first year of intervention it could be demonstrated that large-scale larviciding programmes can reduce malaria transmission in urban Africa. The true programmatic value of larviciding though can only be established through longer-term programmes which are stably financed and allow the capacities of operational teams and infrastructures to mature through direct experience of locally relevant ecological, epidemiological and institutional challenges.

6.7 Competing interests

The programme evaluated in this manuscript is partially supported by Valent BioSciences Corporation, a commercial manufacturer of microbial larvicides. Nevertheless, none of the funders of this work had any role neither in the analysis or interpretation of the results nor in the drafting of the manuscript.

6.8 Authors' contributions

UF, KK, MCC, GW and GFK developed all standard operating procedures concerning larval surveillance and control in a participatory manner with field staff at city, municipal and ward level. YG, PPC, NJG were involved in the development of adult mosquito sampling protocols, field data collection and analyses. KK oversaw all activities implemented by the UMCP. UF, KK and GFK planned and oversaw the larval control intervention. MCC and KK created all databases. SD and DN developed and oversaw the participatory mapping. MJV and EMM helped with protocol refinement based on evaluation of CORPs' performance. DM, MT, SWL, HM and BHS were involved in the overall design of the UMCP and regular review of progress. UF and GFK were involved in the analyses of the data and drafted the manuscript. All authors read and approved the final manuscript.

6.9 Acknowledgements

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7 URBAN AGRICULTURE AND *ANOPHELES* HABITATS IN DAR ES SALAAM, TANZANIA

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7.1 Abstract

A cross-sectional survey of agricultural areas, combined with routinely monitored mosquito larval information, was conducted in urban Dar es Salaam, Tanzania, to investigate how agricultural and geographical features may influence the presence of *Anopheles* larvae. Data were integrated into a geographical information systems framework, and predictors of the presence of *Anopheles* larvae in farming areas were assessed using multivariate logistic regression with independent random effects.

It was found that more than 5% of the study area (total size 16.8 km^2) was used for farming in backyard gardens and larger open spaces. The proportion of habitats containing *Anopheles* larvae was 1.7 times higher in agricultural areas compared to other areas (95% confidence interval = 1.56-1.92). Significant geographic predictors of the presence of *Anopheles* larvae in gardens included location in lowland areas, proximity to river, and relatively impermeable soils. Agriculture-related predictors comprised specific seedbed types, mid-sized gardens, irrigation by wells, as well as cultivation of sugar cane or leafy vegetables. Negative predictors included small garden size, irrigation by tap water, rainfed production and cultivation of leguminous crops or fruit trees.

Although there was an increased chance of finding *Anopheles* larvae in agricultural sites, it was found that breeding sites originated by urban agriculture account for less than a fifth of all breeding sites of malaria vectors in Dar es Salaam. It is suggested that strategies comprising an integrated malaria control effort in malaria-endemic African cities include participatory involvement of farmers by planting shade trees near larval habitats.

7.2 Background

Urban agriculture

The consequences of rapid urbanisation pose enormous challenges for cities, particularly in developing countries of sub-Saharan Africa. Challenges associated with such growth as seen there include high rates of unemployment and scarcity of adequate shelter, food, water, sanitation and environmental protection (Hardoy et al. 2001, Harpham 2008, UN 2008b, UNFPA 2007). One response to the increasing demands is urban and periurban agriculture, i.e. the production (from crop to animal production), processing and distribution of food within and around urban areas (Mougeot 2000b).

Farming in cities is a worldwide phenomenon (Smit et al. 1996), yet it has different functions in industrialised countries as compared to the developing ones. While its role has shifted to a mainly recreational one in the former, it remains an integral part of livelihood and food security in the latter (Drescher 1998, Drescher et al. 2006, Gerstl et al. 2002, Mougeot 2000b). In Tanzania, the annual urban growth rate from 2005-2010 is projected to be 4.2% (UN 2008b) and urban agriculture (UA) appears to have developed and expanded in response to genuine need (Kyessi 1997). People of varied socio-economic status levels practise UA throughout Tanzanian towns and cities (Howorth et al. 2001, Sawio 1993).

In Dar es Salaam UA takes place on public land, private land, residential plots and industrial or institutional areas. In many cases, public land is used without formal agreement or illegally and without secure land rights (Jacobi et al. 2000a). A large number of farmers of open spaces obtained their plots in the first half of the 1970s. During this period of economic crisis, the Tanzanian Government encouraged people in the city to cultivate every available piece of land (Stevenson et al. 1994). The decline of the economy worsened in the 1980s resulting in shortages of basic foodstuff. Urban dwellers responded by engaging in subsistence farming (Briggs 1991) and by 1988, one in five people of working age in Dar es Salaam were involved in some form of UA (Smit et al. 1996). Currently, UA in Dar es Salaam consists of backyard gardening, livestock farming, community gardening, and market-oriented production on open spaces. Vegetables are the most important product (Jacobi et al. 2000a) and most of the leafy vegetables consumed in Dar es Salaam comes from UA within the city (Stevenson et al. 1994). While backyard gardening is most important in terms of the number of households involved (Jacobi et al. 2000a), open space production covers the largest area (4% of the urban area in 1999) (Dongus 2001). UA thus plays an important role in providing food, maintaining green areas, and generating income, yet it may also entail health risks. First, crops can be contaminated with heavy metals or pathogens from industrial or domestic wastewater, from urban solid waste used as fertiliser, or from agro-chemical poisoning (Birley & Lock 1998). Second, UA can provide suitable conditions for mosquito larval development in stagnant water bodies created by irrigation, water storage and drainage, increasing the risk of vector-borne diseases such as malaria (Afrane et al. 2004, Birley & Lock 1998, Keating et al. 2003, Keating et al. 2004).

Urban malaria

Malaria accounts for approximately 1 million deaths worldwide each year, mainly in sub-Saharan Africa (Hay et al. 2005, Snow et al. 2005, WHO 2008). The residents of Dar es Salaam are at risk of contracting malaria (Keiser et al. 2004), and belong to the estimated 2.4 billion of urban population living in areas where malaria transmission is dominated by *Plasmodium falciparum*, cause of the most lethal form of the disease (Guerra et al. 2008). In malaria-endemic areas, urbanisation has major implications for disease transmission patterns (Lines et al. 1994, Warren et al. 1999). Although vector density is typically much lower in urban areas compared to periurban and rural areas (Robert et al. 2003), malaria transmission is nevertheless a significant problem (Donnelly et al. 2005, Hay et al. 2005, Keiser et al. 2004, Trape et al. 1993). In Dar es Salaam, over a million malaria cases are reported by the health facilities every year (Mtasiwa et al. 2003) though malaria is often grossly overreported (Makani et al. 2003, Reyburn et al. 2007, Wang et al. 2006), and a considerable part of the infections might result from travel to rural areas (Wang et al. 2006). Transmission is modest with one infectious bite per person per year, reflected by the moderate average prevalence of 12% (Geissbühler et al. 2009). In Dar es Salaam, 90% of all malaria cases are caused by *P. falciparum* with the main vectors being *Anopheles gambiae sensu strictu* Giles, *An. arabiensis* Patton, *An. funestus* Giles and *An. merus* Dönitz (Castro et al. 2004). However, all *Anopheles* species found in Dar es Salaam are potential malaria vectors (Geissbühler et al. 2009).

UA and malaria

The impact of UA on malaria transmission intensity in cities is not fully understood. In Kumasi, Ghana, higher adult anopheline densities were found in urban areas with agriculture than in those without. However, these UA areas were located in inland valleys that might have more mosquitoes due to their local ecology (Afrane et al. 2004). A report on malaria in Accra, Ghana, compared the prevalence in communities with and without UA concluding that proximity to irrigated, open-spaced, and commercial vegetable production may increase transmission (Klinkenberg et al. 2005), which could potentially play a role in malaria epidemiology (Klinkenberg et al. 2008). Other studies found that certain irrigation practices result in larger mosquito populations (Afrane et al. 2004, Briet et al. 2003, Dolo et al. 2004, Ijumba & Lindsay 2001) but these do not necessarily lead to higher transmission levels (Dolo et al. 2004, Ijumba & Lindsay 2001). In Bouaké, Côte d'Ivoire, Dossou-yovo et al. (1994, 1998) found high anopheline densities but low sporozoite rates in areas bordering rice cultivation, concluding that rice fields did not seem to have notably modified malaria transmission. Robert et al. (1998) concluded from a study on market garden wells in Dakar, Senegal, that although wells served as breeding grounds for anophelines, these sites were not the only in sustaining the mosquito population. In Dar es Salaam, Wang et al. (2006) found that having a small urban agricultural land or garden near the living compound was not associated with malaria infection. However, these surveys were conducted after a long period of drought, when malaria prevalence was exceptionally low. The exact role of UA in malaria transmission thus remains unclear and needs further investigation (Afrane et al. 2004, Wang et al. 2006).

Anopheles breeding sites can be found in all kinds of urban land use, agricultural or not. A variety of studies have found that UA creates breeding sites for anophelines (Afrane et al. 2004, Klinkenberg et al. 2008, Matthys et al. 2006, Trape & Zoulani 1987). However, a study in two Kenyan cities found no association between household level farming and vector breeding sites (Keating et al. 2004). Experiences in large-scale rice irrigation schemes in Mali showed the types and the density of breeding sites varied depending on the rice growing stages, and the related provision of shade (Klinkenberg et al. 2003). Therefore, water management such as intermittent irrigation as well as the adaptation of farming practices may significantly reduce the number of breeding sites in rice fields (Keiser et al. 2002, Klinkenberg et al. 2003, van der Hoek et al. 2001). In Dar es Salaam, Sattler et al. (2005) found that, where the groundwater table was high, seedbeds with small ridges tilled for growing plants with furrows dug between the ridges often contained shallow pools with *Anopheles* larvae. While rice fields, shallow wells and irrigation channels have also been found productive in this sense, malaria transmission in Dar es Salaam seems to be primarily associated with clusters of poorly drained and periurban areas, which often coincide with agricultural land use (Castro et al. 2004, Sattler et al. 2005).

This paper focuses on urban crop production investigating how the presence of *Anopheles* larvae is related to different UA characteristics as well as underlying geographical features in Dar es Salaam, Tanzania.

7.3 Methods

Study area

Dar es Salaam is the largest city and *de facto* capital of Tanzania with an estimated 2.9 million inhabitants in 2007 (UN 2008b). Situated on the shores of the Indian Ocean, large parts of the city are located on coastal plains that are interrupted by a number of river valleys. It has a hot and humid tropical climate with two rainy seasons and is characterised as an area with endemic and perennial malaria (MARA/ARMA 2002). Although the conditions for agriculture are not particularly favourable in terms of soil types and fertility (Sawio 1998), UA is widespread (Jacobi et al. 2000a).

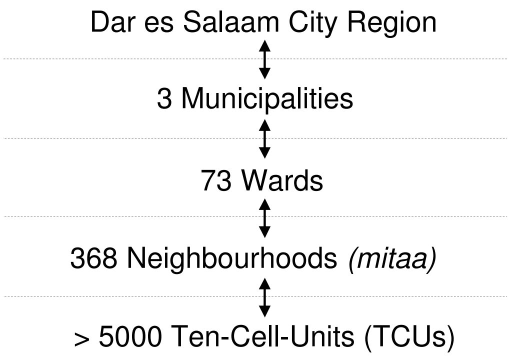

Figure 7.1: Administrative levels and units in Dar es Salaam

Source: National Bureau of Statistics (2003). The number of TCUs is an estimation based on the participatory mapping described in chapter 5.

The city region covers an area of almost 1,400 km^2 (Castro et al. 2004), divided into 73 administrative units called wards (Figure 7.1). Three of those wards, Mikocheni, Buguruni and Kurasini, were chosen for sampling for this study. These areas are located within the urban area of Dar es Salaam between 1 and 10 km away from the city centre. The study area covers a total area of 16.8 km^2 and a population of 128,000 (Figure 7.2) (National Bureau of Statistics 2003). Most of the area is built-up but provides nevertheless excellent breeding sites for mosquitoes with varied aquatic habitats for their eggs, larvae and pupae (Castro et al. 2004, Fillinger et al. 2008, Sattler et al. 2005). The choice of these wards rested on two main reasons: (i) they are representative of Dar es Salaam's geographic and socio-economic characteristics as well as of its urban land use (Dongus et al. 2007); and (ii) the relevant quality-controlled records of the distribution of aquatic-stage mosquitoes (Fillinger et al. 2008) are available from the Dar es Salaam Urban Malaria Control Programme (UMCP). This is the first operational community-based larviciding programme in modern Africa, described in detail elsewhere (Castro et al. 2004, Dongus et al. 2007, Fillinger et al. 2008, Mukabana et al. 2006).

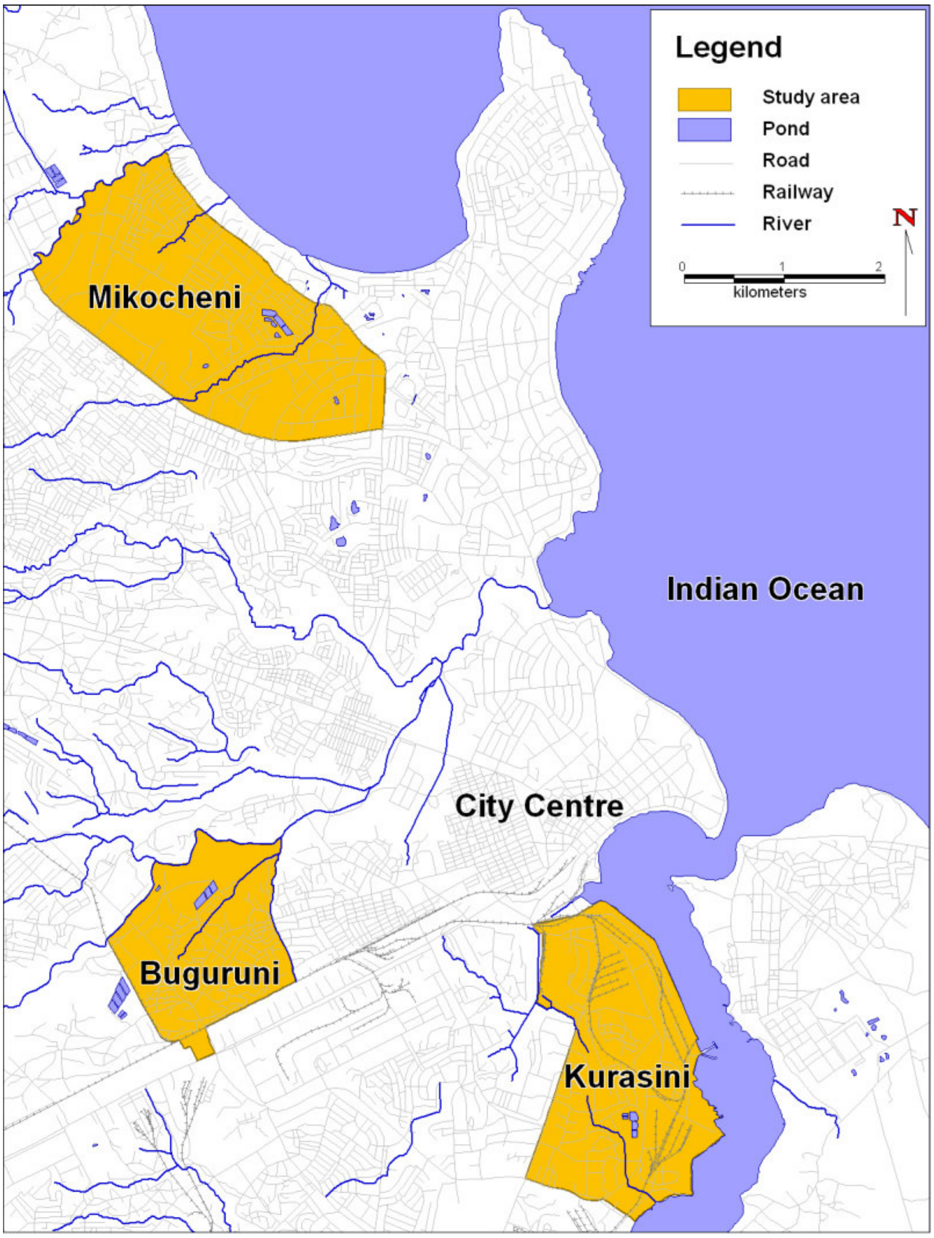

Figure 7.2: Study area

Location of the three wards selected as study areas in Dar es Salaam: Mikocheni, Buguruni and Kurasini

The analysis is based on two datasets: (i) a specific UA survey, and (ii) the routine UMCP larval habitat survey (Fillinger et al. 2008).

UA survey data

Between late June 2005 and early January 2006, the three study wards were first visited and a cross-sectional survey of all agricultural areas used for crop production was conducted. The survey was fully integrated into a participatory mapping of the UMCP target areas (Dongus et al. 2007), which was almost exclusively conducted during the dry periods. Data on agricultural characteristics (the variables are listed and explained in Table 7.1 and Table 7.2) were collected using specific forms. The boundaries of each agricultural area were indicated on laminated A4 colour prints (scale 1:3,000) of digital aerial photographs with a ground resolution 0.5 m (produced by Geospace International, Pretoria, South Africa in 2002). Water bodies located within the agricultural areas were surveyed for the presence of *Anopheles* larvae utilising the same standardised operational protocols as that adopted by the UMCP larval surveillance team (Fillinger et al. 2008). All data were digitised using the geographical information systems (GIS) software MapInfo Professional® 7.0 (MapInfo Corporation, Troy, NY, USA).

UMCP larval habitat data

The UMCP larval habitat data comprise comprehensive longitudinal larval surveillance information with one data entry per four week period (variables used in this study are described in Table 7.1 and Table 7.2). The UMCP data were collected on an operational basis as described in detail by Fillinger et al. (2008). Larval catchers were trained and routine supervision and spot checks were undertaken to monitor and assure the quality of the information. The data were stored in databases created in EpiInfo™ software (Centers for Disease Control and Prevention (CDC), Atlanta, GA, USA), and double-entered.

Table 7.1: Geographical and agricultural explanatory variables which were tested regarding response variables denoting absence/presence of *Anopheles* larvae in agricultural areas

Explanatory variable	Categories / values	Explanations
Topography	Upland Slope Lowland	Subjective categorisation done in the field, relative to surroundings within a distance of 1km. Validated by visual interpretation of a Digital Elevation Model** (ITC Enschede & University of Dortmund 2008). "Upland": higher or same altitude than surroundings in all directions, "lowland": lower altitude than surroundings in at least one direction, "slope": area between upland and lowland.
Land use	Informal settlement Other urban/industrial Planned residential Vacant/agriculture	Data from 2002, available as geographical information systems (GIS) layer**. Selfexplaining category names.
Ward	Mikocheni Buguruni Kurasini	The Dar es Salaam City Region is subdivided into 73 wards. The three "wards" included in this study are located in the urban part of the City Region (Figure 7.2). Categories are the ward names.
Farming site	Backyard garden Open space Unbuilt plot/nursery	"Backyard garden" (home garden): typically but not always near the home of the gardener, within residential areas, generally for subsistence production, maintained by individuals or households who have some access to land (either customary or legal) which they have arranged for themselves (Drescher et al. 2006). "Open space": public or private unbuilt land, for example hazardous lands declared not suitable for construction, road and railway reserves, available land for community use, as well as residential, industrial or institutional plots under-utilised or awaiting development. Open spaces are often used for agricultural activities, generally marketoriented production, and cultivated by more than one farmer (Dongus 2001).
Production type	None Raised beds (*matuta*) Sunken beds Mixed raised & sunken beds	Describes any kind of seedbed arrangements. "None": plants grown on the plain ground, "raised beds": plants grown on ridges with furrows in between, usually to keep the roots dry, "sunken beds": seedbeds with slightly raised borders, usually to maximise water use.
Soil type	Sandy Loamy or clayey	The soil type was determined by a simple finger test on the spot: rubbing the soil between fingertips in order to assess the texture. Twenty-nine observations lack any data for this variable.
Manure	None Cow/poultry/pig/goat or other manure	If a farmer was present, he or she was asked whether and what kind of manure is used. If no one was present, the type of manure used was determined visually or by its typical smell.
Irrigation source	Well Only rainfed Tap water Drain/ditch/standing groundwater/river/ stream or other	If a farmer was present, he or she was asked whether and what kind of irrigation is used. If no one was present, the irrigation type was determined visually.

Size	>400m^2 101-400m^2 ≤100m^2	All agricultural areas were digitised in a GIS, so their exact sizes are known.
Distance to rivers/streams	≤200m 201-500m >500m	Rivers/streams were digitised from the 1992 Dar es Salaam City Map 1:20,000. Inaccuracies were corrected on the basis of the 2002 aerial photographs. Buffer zones corresponding to the distance categories (e.g. ≤200 m) were assigned in the GIS. Agricultural areas were then assigned a certain distance category if their geometric centre (centroids) was located within the respective buffer zone.
Distance to drains	≤200m 201-500m >500m	Drains were digitised from 1992 Cadastral Maps 1:2,500. Inaccuracies due to new constructions were corrected on the basis of the 2002 aerial photographs and Google Earth imagery. Buffer zones corresponding to the distance categories (e.g. ≤200 m) were assigned in the GIS. Agricultural areas were then assigned a certain distance category if their geometric centre (centroids) was located within the respective buffer zone.
Distance to large standing water bodies	≤200m 201-500m >500m	Standing water bodies were digitised from the 1992 Dar es Salaam City Map 1:20,000. Inaccuracies e.g. due to new constructions were corrected on the basis of the 2002 aerial photographs and Google Earth imagery. Buffer zones corresponding to the distance categories (e.g. ≤200 m) were assigned in the GIS. Agricultural areas were then assigned a certain distance category if their geometric centre (centroids) was located within the respective buffer zone.
Cereals*	Absent /present	Maize, sorghum
Rice*	Absent /present	Rice
Leafy vegetables*	Absent /present	E.g., chinese cabbage, lettuce, spinach, sweet potato leaves, amaranth
Other vegetables*	Absent /present	E.g., cucumber, eggplant, tomatoes, watermelon, pumpkin, carrots, onion, sweet pepper, hot pepper, okra
Fruits*	Absent /present	E.g., avocado, citrus, mango, pawpaw, pineapple, lemon, banana, cashew nuts, guava, passion
Oilseed crops*	Absent /present	E.g., coconuts, sunflowers, groundnuts
Root crops*	Absent /present	Sweet potato, cassava, cassava leaves, yams
Leguminous crops*	Absent /present	Cowpeas, pigeon peas
Sugar cane*	Absent /present	Sugar cane
Other crops*	Absent /present	E.g., flowers, tobacco, Guatemala grass

* Variables for crops assigned based on the “Indicative Crop Classification” (Food and Agriculture Organization of the UN) (FAO 2005)
** Information provided by ITC Enschede & Dortmund University

Table 7.2: Response variables for which geographical and agricultural explanatory variables were tested

Response variable	Categories/values	Explanations
Anopheles UA survey	Absent /present	Presence of *Anopheles* larvae (any stage). Data source: UA survey. Not distinguishing seasons.
Anopheles UMCP	Absent /present	Presence of *Anopheles* larvae (any stage). Data source: UMCP larval database. Distinguishing wet and dry seasons.
Anopheles late UMCP	Absent /present	Presence of late instar *Anopheles* larvae. Data source: UMCP larval database. Distinguishing wet and dry seasons.
Pupae UMCP	Absent /present	Presence of pupae (*Anopheles* and/or *Culex*). Data source: UMCP larval database. Distinguishing wet and dry seasons.

Linking of UA data and UMCP larval data

In order to not only receive information about larval presence in the agricultural areas for one point in time, but for both the dry and wet seasons, the UA survey data were matched with the UMCP larval data. The agricultural data of each area identified in the UA survey were matched with two observations from the UMCP larval database, representing data from the wet and dry seasons and collected nearest in time to the UA survey observation. This made it possible to incorporate the aspect of rainfall seasonality into the cross-sectional data. All UMCP larval observations, made between March 2005 and February 2006, were assigned either to a wet or a dry season period based on daily rainfall data from the Tanzania Meteorological Agency (http://www.meteo.go.tz) collected at the Dar es Salaam airport station. The wet season periods (average weekly rainfall above 25 mm) included March 9-May 28, 2005; October 18-November 25, 2005; and February 12-28, 2006. The dry season periods (average weekly rainfall below 2.5 mm) included May 29-October 17, 2005; and November 26, 2005 to February 11, 2006 (Figure 7.3). The maximum time between the UA survey and the corresponding UMCP larval data was one month or less in 87% of the UMCP dry season observations (median = 12 days), and three months or less in 88% of the UMCP wet season observations (median = 59 days).

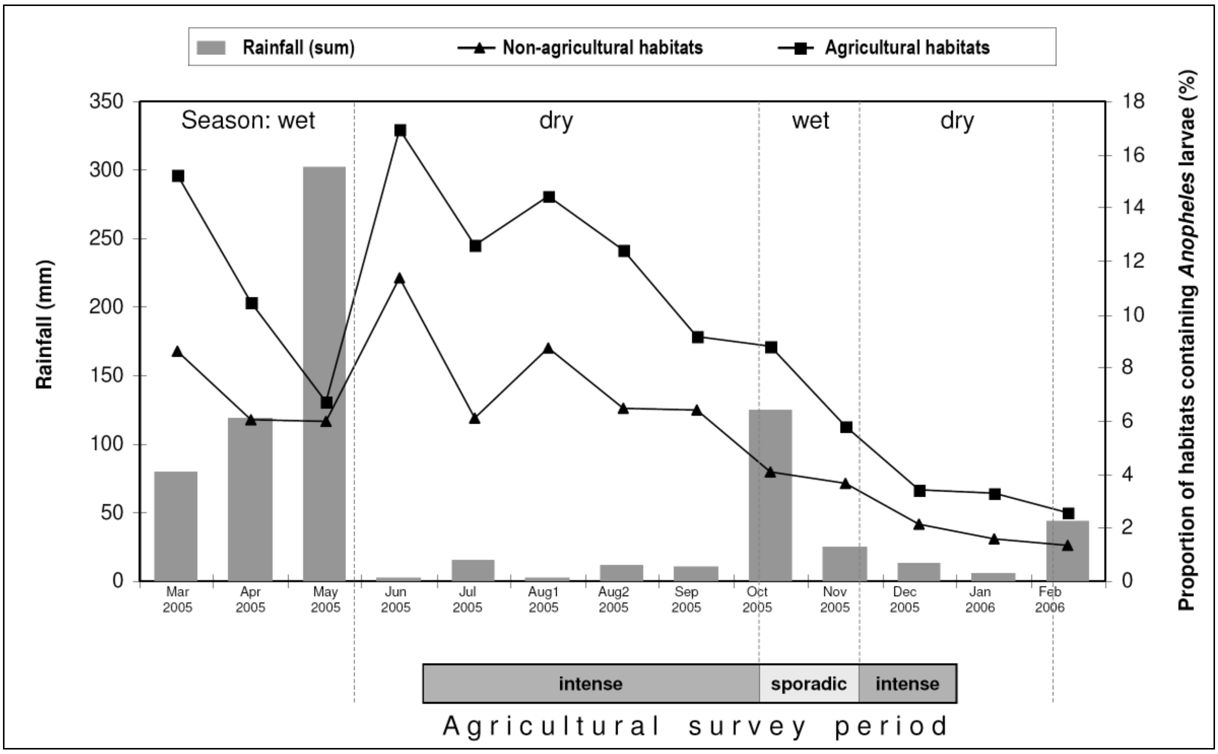

Figure 7.3: Seasonality and proportions of habitats with *Anopheles* larvae

X-axis: period of the UMCP larval data and the UA survey. Y-axis: rainfall in mm (grey bars); proportions of habitats containing *Anopheles* larvae in agricultural areas (upper line) and non-agricultural areas (lower line). Larval proportions are based on UMCP larval data.

The UA survey found a total of 623 agricultural areas in the study area, with sizes ranging from 10 to almost 66,000 m^2, covering a total area of 0.9 km^2. From these, 201 areas had to be dropped because no observations were available for them in the UMCP larval database. These areas were mostly rainfed small gardens located in upland or slope areas (Figure 7.6A). In addition, 17 gardens were excluded because they only had observations for one of the two seasons. Another 33 areas had to be excluded because their corresponding UMCP larval data only covered periods after the commencement of larvicide use in March 2006 (Fillinger et al. 2008, Geissbühler et al. 2009). Unfortunately, these 33 areas, located in the valley of the Msimbazi River in Buguruni, constituted the largest agricultural cluster in the study area. Hence, the study sample comprised 372 individual agricultural areas covering a total of 0.2 km^2 (covering 1.2% of the total surface of the study area).

Geographical data

Available geographical data were assembled. Some of these were used for visual interpretation (e.g. roads and railway lines), while other data were utilised for statistical analysis (e.g. land use and hydrological information). Land use classes and distances to hydrological features (e.g. rivers) were assigned based on the centroid locations (geometric centres) of each agricultural area. In order to determine the distances, buffer zones were assigned around the various hydrological features (Table 7.1). A digital elevation model (DEM) was used for visual interpretation and validation of the topographical data collected in the UA survey. The DEM as well as the roads and land use data were provided by the International Institute for Geo-Information Science and Earth Observation (ITC) Enschede, The Netherlands, and the University of Dortmund, Germany (2008).

Statistical methods

Statistical analysis was done with the STATA® software (version 9.0, Stata Corporation, College Station, TX, USA), and complemented with visual interpretation of maps produced with MapInfo and ArcGIS (version 9.2, ESRI, Redlands, CA, USA). Multiple models were fitted using a stepwise (backward selection and inclusion criteria: p<0.2) multivariate, logistic regression procedure with independent random effects. The following statistical model specifications were employed:

Let Y_i be the binary response corresponding to the presence of *Anopheles* larvae at site i, $i = 1,...n$, taking value 1 if *Anopheles* larvae are present and 0 otherwise. Let $X_i = (X_{i1},..., X_{ip})^T$ be the vector of p associated geographical and agricultural predictors observed at location i. We assume that Y_i are Bernoulli distributed $Y_i \sim Ber(p_i)$ with presence probability p_i given by $\log it(p_i) = \beta_0 + \sum_{j=1}^{p} X_{ij}\beta_j$.

To take into account potential clustering, random effects ε_i were introduced at each site i, that is $\log it(p_i) = \beta_0 + \sum_{j=1}^{p} X_{ij}\beta_j + \varepsilon_i$. The ε_i's were assumed independent and were modelled with a mean 0 normal distribution with variance τ^2.

The response variables for all models denoted presence or absence of (i) *Anopheles* larvae, (ii) late instar (development stage) *Anopheles* larvae, and (iii) pupae of any kind of mosquito species. Three response variables were based on UMCP larval data, distinguishing wet and dry seasons, and one response variable was exclusively based on UA survey data. Almost all (99%; n = 367) of the UA survey observations were made in the dry season, with only 1% (n = 5) in the wet season (see Table 7.1 and Table 7.2 for a list and description of the explanatory and response variables). Because of the small sample size, data from individual wards were combined in one model. Correlations between explanatory variables were assessed using Fisher and $\chi 2$ tests. Interaction terms between production type and types of crops were included in the regression models to test for heterogeneity in the effect of various crops.

7.4 Results

Typology of agricultural areas

The UA survey revealed that a total of 0.9 km^2 equal to 5.5% of the study area was used for urban crop farming at the time of the study. The most common farming sites were backyard gardens and open spaces (Table 7.1 and Figure 7.4). Garden sizes ranged from as little as 15 m^2 to 15,000 m^2 (mean = 550 m^2, median = 202 m^2). In planned residential areas large backyard gardens were most common, while small backyard gardens were more common in informal settlements. Areas designated for industrial purposes were often used for open-space farming. Less than 10% of all gardens were found in vacant land not considered to be part of residential or industrial areas. Most gardens were located in upland areas (70%), mainly with sandy soils. Half of the gardens in the lowland areas had loamy or clayey soils. Proximity to rivers was neither correlated to number of nor to sizes of gardens.

Slightly more than half of all gardens were irrigated. The non-irrigated gardens were particularly seen in informal settlements which thus relied on rainfall for water. Otherwise, 30% of the gardens were irrigated with tap water, which was the most common source of irrigation in planned residential areas, while 20% used dug earth wells or cemented ones as source of irrigation. Water from rivers, drains and standing groundwater was utilised in only 4% of all cases. In more than a third of the gardens, some kind of manure was applied as fertiliser with poultry and cow dung being the most popular ones. Almost two-thirds of all gardens, and more than 80% of those in informal settlements smaller than 100 m^2, did not have any specific production type; there were no seedbed arrangements and crops were simply planted into the plain soil. In contrast, 18% of the gardens consisted of sunken beds only, 13% of raised beds only, and another 4% had both sunken and raised beds.

The most common classes of crops grown were vegetables (leafy as well as non-leafy), fruit and root crops, that were found in about 60% of all gardens. Leguminous crops[23] (42%), sugar cane (24%) and cereals (23%) were also frequently present. Oilseed crops were found in 7% of all gardens. Only 1% of gardens grew rice but this picture would have been different in the wet season when rice production is popular, especially in the river valleys. In most gardens, three or more different crop classes were present.

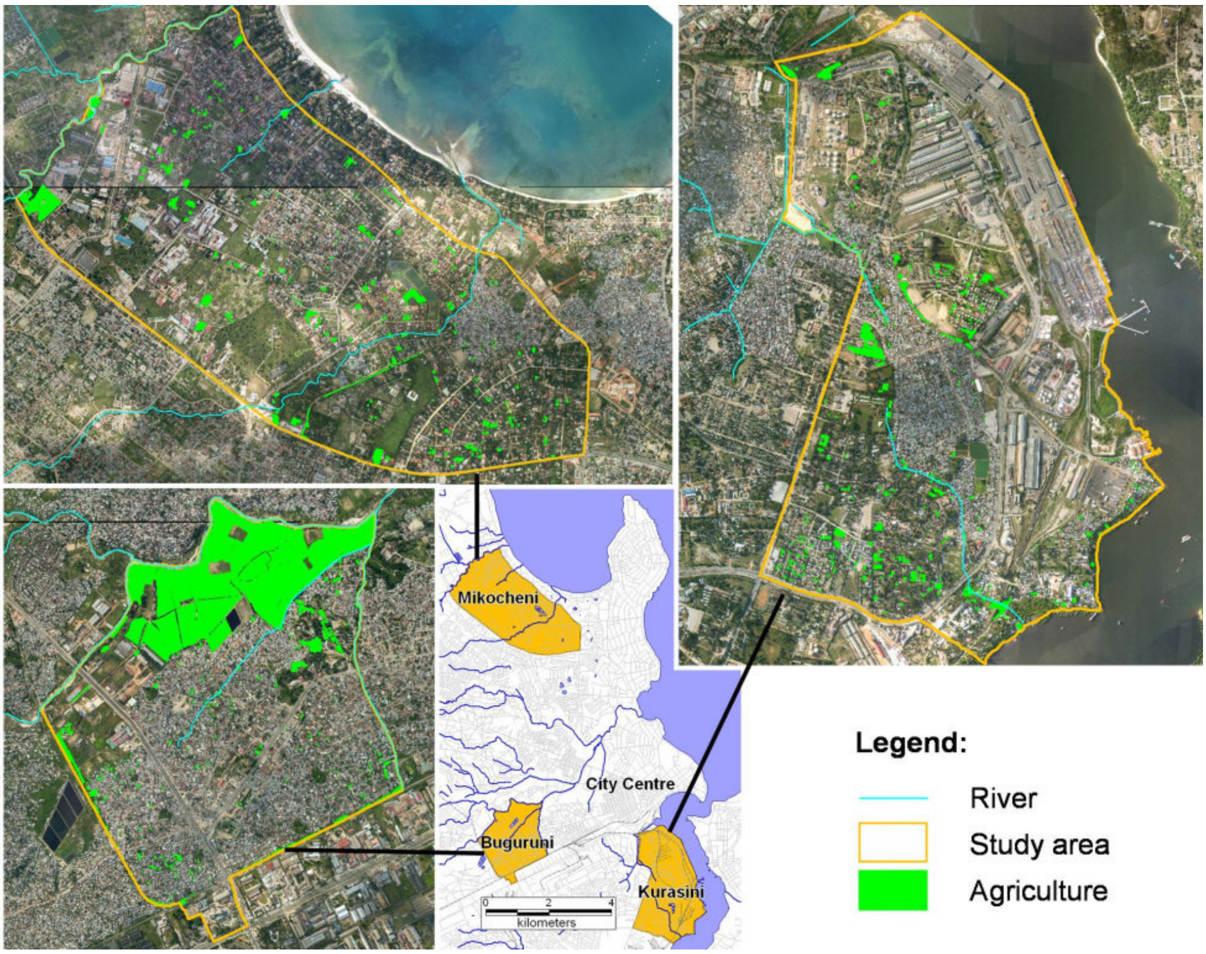

Figure 7.4: Map of urban agricultural areas in Dar es Salaam

Location and extent of urban agricultural areas in the three study wards. Background: aerial image from 2002.

[23] examples for leguminous crops in Dar es Salaam are cowpeas and pigeon peas

Urban agriculture and *Anopheles* larvae

The UMCP survey results, which were linked to the UA survey data, found *Anopheles* larvae in 11% of all plots with agriculture during the wet periods, and in 17% of all plots (subunits of ten-cell-units; Dongus et al. 2007) with agriculture during the dry periods. The UA survey, mostly conducted during dry periods, showed a lower level of occupancy with *Anopheles* larvae (12%). The discrepancies may be a result of small temporal variations in larval density. Figure 7.3 shows the seasonality observed in the UMCP larval dataset and the period of the agricultural survey. Figure 7.5 shows a map of the agricultural areas with and without *Anopheles* larvae.

The largest number of breeding sites with *Anopheles* larvae in Dar es Salaam was not found to be related to agriculture but instead to drains, ditches, swamps and puddles in non-agricultural areas. During March 2005 to February 2006, 11% of all water bodies found by the UMCP in the studied wards were located in agricultural areas and 17% of all habitats containing *Anopheles* larvae were found in those areas. Therefore, although agricultural areas were not the most frequent potential habitat, they were more productive than the others. This is illustrated by the finding that throughout all seasons of the year, the proportion of habitats containing *Anopheles* larvae was higher in plots with agriculture compared to plots without agriculture. The average proportion over the year was 1.7 times higher in agricultural plots (95% confidence interval (CI) = 1.56-1.92). Figure 7.3 shows the proportions of habitats containing larvae among all habitats plotted against those found in agricultural plots.

Geographical features

Topography, location, hydrology and soil type were the most significant geographical features associated with the presence of *Anopheles* larvae. Plots with farming in lowland areas were far more likely to contain breeding sites with *Anopheles* larvae than upland farming areas (dry season: odds ratio (OR) = 14.56; 95% CI = 4.02-52.82; $p<0.001$) (Table 7.3 and Table 7.4). Compared to the Mikocheni ward, the odds of finding *Anopheles* larvae were lower in the Buguruni gardens (dry season: OR = 0.02; 95% CI = 0.00-0.11; $p<0.001$), and also in Kurasini. During the dry season, the chance of finding late instar *Anopheles* larvae decreased at distances further than 500 m away compared to distances less than 200 m away from rivers (OR = 0.20; 95% CI = 0.06-0.63; $p = 0.006$). A similar relation applied for ponds. Gardens on loamy and clayey soils showed a higher chance for *Anopheles* larvae than those on sandy soils (OR = 9.28; 95% CI = 3.05-28.18; $p<0.001$). Regarding land use, gardens in planned

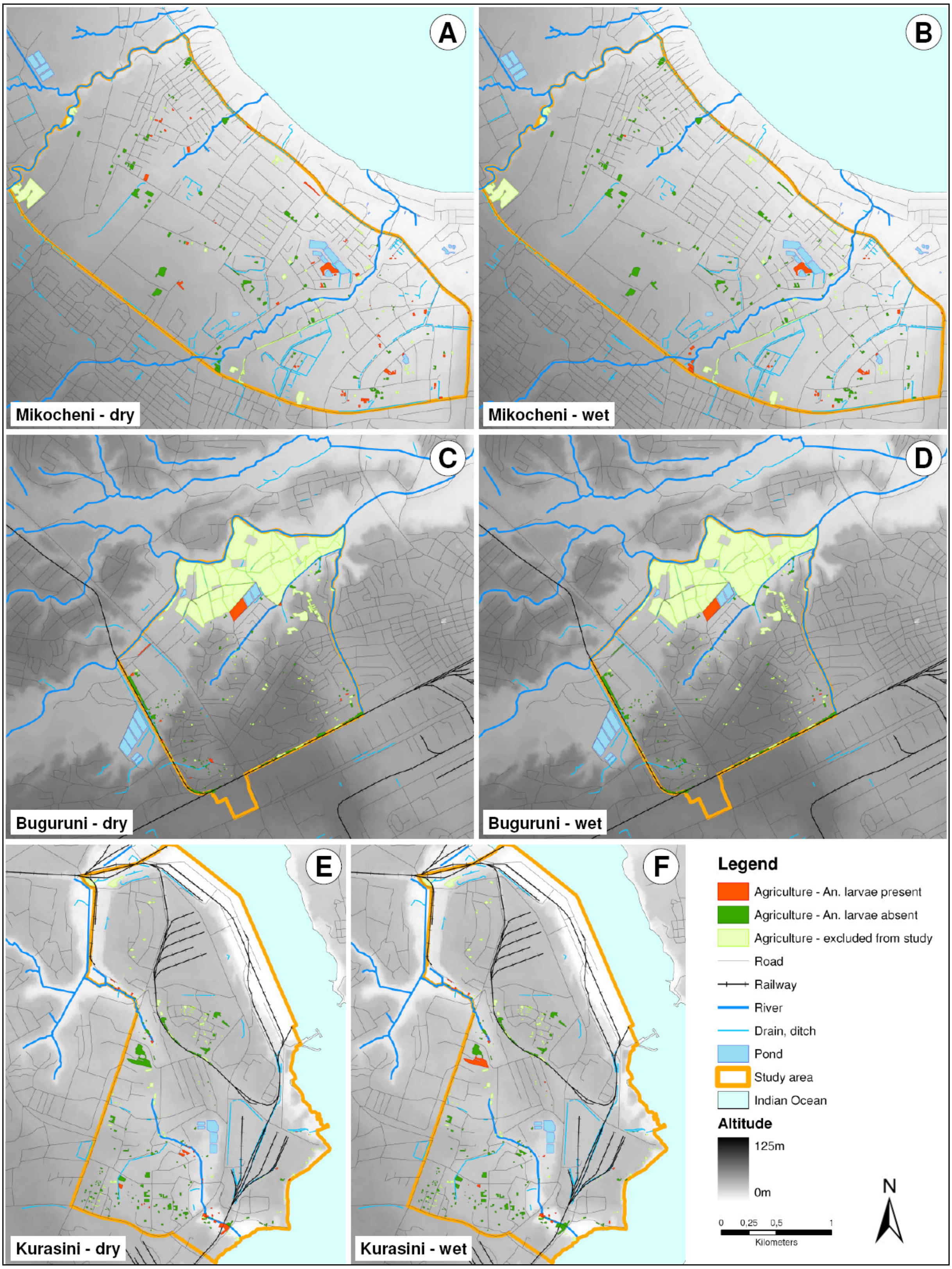

Figure 7.5: Map of agricultural areas and *Anopheles* larvae in Dar es Salaam

Map of agricultural areas in the three study wards, indicating presence (red) and absence (dark green) of *Anopheles* larvae in the wet and the dry season periods, as well as agricultural areas excluded from the study (light green). Results from UA survey and UMCP larval data are combined.

Table 7.3: Results of multivariate logistic regression models (dry season)

	Variable	n	*Anopheles* UA survey			*Anopheles* UMCP dry			*Anopheles* late UMCP dry			Pupae UMCP dry		
			OR	95% CI	p	OR	95% CI	p	OR	95% CI	p	OR	95% CI	p
Geographical features	**Topography**													
	Upland	261				1								
	Slope area	31				**10.30**	**2.37, 44.81**	***0.002**						
	Lowland	80				**14.56**	**4.02, 52.82**	***<0.001**						
	Land use													
	Informal settlement	130												
	Other urban/industrial	60												
	Planned residential	151												
	Vacant/agriculture	31												
	Location (ward)													
	Mikocheni	117				1								
	Buguruni	103				**0.02**	**0.00, 0.11**	***<0.001**						
	Kurasini	151				**0.12**	**0.03, 0.42**	***0.001**						
	Distance to rivers													
	≤200m	129	1						1			1		
	201-500m	103	0.38	0.09, 1.58	0.182				0.50	0.18, 1.39	0.182	**0.26**	**0.11, 0.64**	***0.003**
	>500m	140	2.46	0.78, 7.73	0.124				**0.20**	**0.06, 0.63**	**0.006**	**0.20**	**0.09, 0.47**	***0.000**
	Distance to drains													
	≤200m	224												
	201-500m	133												
	>500m	15												
	Distance to ponds													
	≤200m	47							1			1		
	201-500m	98							**0.28**	**0.08, 0.96**	**[b]0.043**	0.74	0.28, 1.93	0.538
	>500m	227							**0.26**	**0.09, 0.78**	**[b]0.017**	**0.26**	**0.11, 0.66**	**0.004**
	Soil type[a]													
	Sandy	255	1									1		
	Loamy or clayey	88	**9.28**	**3.05, 28.18**	***<0.001**							**3.34**	**1.52, 7.36**	**0.003**
Agricultural features	**Size of garden**													
	>400m^2	116	1						1			1		
	101-400m^2	153	1.72	0.57, 5.18	0.331				**4.50**	**1.49, 13.56**	**0.008**	**3.12**	**1.24, 7.87**	**0.016**
	≤100m^2	103	**0.08**	**0.01, 0.82**	**0.034**				2.61	0.65, 10.44	0.176	**3.79**	**1.32, 10.90**	**0.013**
	Production type													
	None	244	1			1			1					
	Raised beds (*matuta*)	48	0.46	0.10, 2.13	0.319	0.57	0.16, 2.07	0.397	0.40	0.08, 1.90	0.248			
	Sunken beds	67	**5.37**	**1.52, 18.95**	**0.009**	**3.29**	**1.34, 8.06**	**0.009**	**5.54**	**2.01, 15.33**	**0.001**			
	Mixed sunken/raised	13	**16.24**	**2.07, 127.25**	**0.008**	1.37	0.22, 8.58	0.740	6.68	0.84, 53.25	0.073			
	Irrigation source													
	Well	76	1									1		
	Only rainfed	169	**0.22**	**0.06, 0.73**	***0.013**							1.12	0.45, 2.78	0.810
	Tap water	111	**0.16**	**0.04, 0.58**	***0.005**							0.41	0.15, 1.13	0.086
	Drain/river/st. water	16	4.58	0.77, 27.46	*0.095							4.08	0.95, 17.50	0.059
	Crop diversity													
	0-2 crop classes	107				1						1		
	3-4 crop classes	169				**0.33**	**0.12, 0.91**	**0.032**				1.83	0.72, 4.65	0.202
	5-8 crop classes	96				**0.20**	**0.05, 0.77**	**0.020**				**6.82**	**1.62, 28.62**	**0.009**
	Crop classes													
	Cereals	84										**0.39**	**0.15, 0.97**	**0.043**
	Rice	5	**29.93**	**1.95, 459.64**	**0.015**									
	Leafy vegetables	232				**2.84**	**1.07, 7.53**	**0.036**				**0.37**	**0.16, 0.86**	**0.021**
	Fruits	234	0.37	0.13, 1.05	[b]0.062							**0.44**	**0.19, 1.00**	**0.050**
	Leguminous crops	158												
	Sugar cane	91	**4.25**	**1.37, 13.21**	**0.012**									
	R^2 ***		0.46			0.25			0.22			0.28		

Multivariate logistic regression models after stepwise selection of variables, with independent random effects. OR=Odds Ratio, 95% CI=95% Confidence Interval, p=p-value. Results are only shown for variables with p<0.05 in the Likelihood-Ratio-Test (LR-Test). Bold: p<0.05.

[a] 29 observations of variable soil type are lacking the respective code

[b] borderline significant (0.05<p<0.06 in LR-Test)

[*] variables with p<0.001 in Likelihood-Ratio-Test

[***] taken from corresponding multivariate logistic regression model without independent random effect

Table 7.4: Results of multivariate logistic regression models (wet season)

Variable	n	*Anopheles* UMCP wet			*Anopheles* late UMCP wet			Pupae UMCP wet		
		OR	95% CI	p	OR	95% CI	p	OR	95% CI	p
Geographical features										
Topography										
Upland	261	1								
Slope area	31	0.21	0.00, 16.29	0.479						
Lowland	80	24.80	0.46, 1349.15	0.115						
Land use										
Informal settlement	130	1			1					
Other urban/industrial	60	26.46	0.51, 1380	0.104	1.44	0.32, 6.52	0.635			
Planned residential	151	1.36	0.08, 22.34	0.831	**0.14**	**0.02, 0.93**	**0.042**			
Vacant/agriculture	31	1.11	0.05, 25.28	0.946	0.92	0.20, 4.34	0.919			
Location (ward)										
Mikocheni	117	1								
Buguruni	103	0.00	0.00, 1.35	*0.060						
Kurasini	151	0.24	0.01, 3.77	*0.307						
Distance to rivers										
≤200m	129							1		
201-500m	103							**0.27**	**0.10, 0.74**	**0.011**
>500m	140							**0.25**	**0.10, 0.60**	**0.002**
Distance to drains										
≤200m	224	1								
201-500m	133	0.34	0.05, 2.49	0.287						
>500m	15	111.92	0.29, 42537	0.120						
Distance to ponds										
≤200m	47									
201-500m	98									
>500m	227									
Soil type[a]										
Sandy	255									
Loamy or clayey	88									
Agricultural features										
Size of garden										
>400m^2	116									
101-400m^2	153									
≤100m^2	103									
Production type										
None	244							1		
Raised beds (*matuta*)	48							**3.00**	**1.06, 8.48**	**0.038**
Sunken beds	67							**3.60**	**1.53, 8.44**	**0.003**
Mixed sunken/raised	13							**8.56**	**1.87, 39.23**	**0.006**
Irrigation source										
Well	76	1			1					
Only rainfed	169	0.41	0.05, 3.48	0.415	0.26	0.05, 1.35	*0.109			
Tap water	111	0.02	0.00, 1.64	0.080	**0.09**	**0.01, 0.55**	***0.009**			
Drain/river/st. water	16	6.03	0.19, 187.3	0.305	3.18	0.67, 15.13	*0.146			
Crop diversity										
0-2 crop classes	107				1					
3-4 crop classes	169				**5.89**	**1.01, 34.25**	**[c]0.048**			
5-8 crop classes	96				**16.01**	**1.74, 147.1**	**[c]0.014**			
Crop classes										
Cereals	84									
Rice	5									
Leafy vegetables	232	10.29	0.60, 176.17	0.108						
Fruits	234									
Leguminous crops	158				**0.25**	**0.08, 0.81**	**0.020**	**0.38**	**0.17, 0.85**	**0.019**
Sugar cane	91							**2.89**	**1.31, 6.36**	**0.009**
R^2 ***		0.28			0.33			0.15		

Multivariate logistic regression models after stepwise selection of variables, with independent random effects. OR=Odds Ratio, 95% CI=95% Confidence Interval, p=p-value. Results are only shown for variables with p<0.05 in the Likelihood-Ratio-Test (LR-Test). Bold: p<0.05.

[a] 29 observations of variable soil type are lacking the respective code

[c] LR-Test does not converge; variable significant in model without random effect, same OR & p-values

* variables with p<0.001 in Likelihood-Ratio-Test

*** taken from corresponding multivariate logistic regression model without independent random effect residential areas had the lowest odds for late instar *Anopheles* larvae (wet season: OR = 0.14; 95% CI = 0.02-0.93; p = 0.042). Gardens in industrial areas and vacant land, not designated for any kind of construction purposes, were not significant.

Agricultural features

Gardens that fully relied on rainfall had a much lower chance to contain *Anopheles* larvae compared to gardens with any type of well for irrigation (Figure 7.6D) (dry season: OR = 0.22; 95% CI = 0.06-0.73; p = 0.013). Approximately half of the agricultural breeding sites that contained *Anopheles* larvae in the UA survey were wells. The odds were even lower where tap water was used for irrigation (dry season: OR = 0.16; 95% CI = 0.04-0.58; p = 0.005; wet season: late instar: OR = 0.09; 95% CI = 0.01-0.55; p = 0.009). Although only approaching significance because of the low number of observations, other irrigation sources such as water from drains/ditches and standing groundwater in agricultural areas seemed to greatly increase the probability of *Anopheles* larvae presence.

While the exclusive presence of raised beds (*matuta* in Kiswahili, i.e. ridges for planting crops such as sweet potato that are often made on grounds with a high water table) was significant only regarding pupae (wet season: OR = 3.0; 95% CI = 1.06-8.48; p = 0.038), plots with only sunken beds were associated with a higher probability of *Anopheles* breeding in the dry season (OR = 5.37; 95% CI = 1.52-18.95; p = 0.009; all compared to gardens without any kind of seedbed arrangements). Plots with mid-sized gardens (101-400 m^2) had a higher chance of late instar *Anopheles* larvae compared to larger agricultural areas (dry season: OR = 4.50; 95% CI = 1.49-13.56; p = 0.008). The smallest odds were found in small gardens of 100 m^2 maximum size (dry season: OR = 0.08; 95% CI = 0.01-0.82; p = 0.034).

The growing of sugar cane (OR = 4.25; 95% CI = 1.37-13.21; p = 0.012) and leafy vegetables in the dry season was associated with relatively high odds of larvae presence (though less with regard to vegetables). However, the cultivation of leguminous crops (wet season: late instar OR = 0.25; 95% CI = 0.08-0.81; p = 0.020) was correlated with a relatively low probability of larvae presence. Although not significant, the same may apply for the cultivation of fruit (dry season: OR = 0.37; 95% CI = 0.13-1.05; p = 0.062). Oilseed crops such as coconut trees, root crops, non-leafy vegetables and other crops were not significant. Crop diversity lead to different results depending on the season, i.e. in the dry season, the chance to find larvae decreased where three or more crop classes were present within an agricultural area, whereas the opposite was the case during the wet season. Lastly, interaction terms between type of production and type of crop were not significant, suggesting that there was no heterogeneity in the effect of varied crops.

Figure 7.6: Pictures of urban agriculture in Dar es Salaam

A – small rainfed backyard garden in Buguruni, upland location in informal settlement, sandy soil, no seedbed arrangements, visible crops: leafy vegetables and sugar cane; B – large open space garden in Buguruni (river valley), lowland area, loamy soil, sunken beds, visible crops: leafy vegetables, oilseed crops, fruit; C – raised beds (*matuta*) with standing water between ridges in Mikocheni, visible crops: cereals and fruit; D – dug well for irrigation in Buguruni, lowland area.

7.5 Discussion

UA is only one among many other types of land use that can enable larval development of *Anopheles* mosquitoes in cities. More than 80% of all habitats with *Anopheles* larvae in urban Dar es Salaam are located in areas without agricultural activities. However, farming and the presence of *Anopheles* larvae are correlated. Cultivated areas are 1.7 times more likely than others to contain breeding habitats with *Anopheles* larvae. In order to explore the underlying reasons that lead to this situation, factors related to presence of *Anopheles* larvae in UA areas were investigated. Apart from geographical factors that have been examined previously (Balls et al. 2004, Majambere et al. 2008, Matthys et al. 2006, Sattler et al. 2005, Zhou et al. 2007), a range of agricultural features at a partly unprecedented level of detail in terms of crops was included in the analysis. Moreover, to our knowledge, this is the first comprehensive mapping of UA in an African city, notably the inclusion of backyard gardens.

Compared to findings from mountainous areas (Balls et al. 2004, Cohen et al. 2008), this study reveals that topography matters even at differences less than 10 m. As a matter of principle, the topography corresponds with the hydrological conditions in an area. Rivers and streams accumulate fine grained soil particles in their floodplains. Loamy and clayey soils are thus usually found in lowlands, whereas more permeable sandy soils are more frequent in upland areas. The groundwater table is generally higher in lowland areas compared to their surroundings. Therefore, areas in lowlands and in close proximity to rivers or ponds are more likely to contain breeding sites than others. This was particularly obvious in Kurasini (Figure 7.5). All factors mentioned are beneficial for agriculture, and therefore likely to be a main reason for the presence of agriculture in the first place, particularly the case in floodplains that are unsuitable for construction purposes. One can argue that such local ecological conditions are simultaneously ideal for both *Anopheles* larvae and for agriculture. Recent evidence from coastal towns in Kenya supports this finding, showing that agriculture *per se* had no detectable influence when such environmental variables were controlled for (Keating et al. 2004). Furthermore, environmental variables such as shade, substrate and vegetation were the best predictors for the presence of the three major vector species in these urban centres (Jacob et al. 2005). Untouched by any human activity, the natural vegetation of such areas may provide less favourable conditions for *Anopheles* larvae (Lindblade et al. 2000, Munga et al. 2006), especially if closed leafy canopies or other vegetation of sufficient density prevent sunlight from reaching the soil. The only natural vegetation still existing in our study area occurred in a few isolated mangroves in Kurasini.

Different geographic and socio-economic characteristics of the three areas investigated may explain the distinct results for each ward. Mikocheni had the highest odds of finding gardens with larvae. This might be explained by its very homogenous topography with limited surface runoff, and thus higher impact of loamy and clayey soils. The gardens in Mikocheni were relatively large in size as enough space was available in undeveloped industrial plots and backyards in planned residential areas. In contrast to the other two wards, the larval data for Mikocheni used in the analysis were predominantly from the first half of the agricultural survey, coinciding with a period of relatively high larval densities (Figure 7.3). Buguruni showed the lowest odds of finding larvae. To a large extent this can be explained by the fact that the large agricultural area located in the river valley that contains many potential habitats had to be excluded from the analysis. This valley serves as natural drainage for the remaining parts of the ward, mostly upland areas with permeable sandy soils and limited space for gardens due to the dense informal settlement structure. Kurasini had the most diverse terrain and the highest impact from topography. The fact that the probability to find larvae in gardens was found to be lower than in Mikocheni may be explained by the different runoff situation that concentrates surface and ground water to particular areas and the less favourable water-holding capacity by the predominantly sandy soils (89% of gardens in Kurasini, only 45% in Mikocheni). Another reason might be pollution by the petrol and harbour industry in Kurasini.

Agriculture using raised beds (*matuta*) (Figure 7.6C) had no significant impact. This cannot be explained by accidental disproportionate exclusion of such areas in the analysis, such as the large areas in the river valley in Buguruni. In fact, the excluded observations actually had a lower proportion of areas with raised beds (8%, n = 19) than those included (13%, n = 48). The presence of sunken beds with slightly raised borders to maximise water use (Figure 7.6B), however, was clearly correlated to increased presence of larvae. Importantly, in plots with sunken or raised beds, most of the larvae were in wells and not found in seedbeds or in the ridges between them. Nevertheless, considering contrary previous findings (Castro et al. 2004, Sattler et al. 2005, Sawio 1998), the importance of raised beds as *Anopheles* breeding sites should not be underestimated.

Dug earth wells (Figure 7.6D) often contained *Anopheles* larvae, especially if they were large enough to allow parts of the surface to remain undisturbed by irrigation activities. The largest risk factor related to irrigation, however, seemed to be a groundwater table at such a high level that surface water does not drain away or evaporate for long periods. The majority of gardens in such areas contained *Anopheles* larvae. Soil moisture in general has been shown to play a crucial role (Patz et al. 1998). In contrast, purely rainfed gardens and those that are irrigated all year long by tap water were very unlikely to contain larvae suggesting minimal malaria risk. Although water in blocked drains or ditches sometimes contains *Anopheles* larvae, it is often polluted and a typical breeding site for *Culex* larvae, which probably contributes to the high odds of finding pupae in such habitats.

The size of an agricultural area appears to be a logical factor contributing to larval presence, as the likelihood of finding breeding sites increases with the size of an area. At the same time, the size of a garden is related to the number of farmers. While gardens less than 400 m^2 in size are usually cultivated by one farmer, open spaces are often cultivated by several farmers jointly, especially if larger than 1,000 m^2 (Dongus 2001, Jacobi et al. 2000a). In Dar es Salaam, while gardens with a size below 100 m^2 had a significantly smaller probability to contain larvae compared to larger gardens, the most likely gardens to have larvae were the mid-sized ones (100-400 m^2) rather than the largest ones. A possible explanation for this observation might be the intensive use of irrigation in large agricultural areas where several farmers often share the same well. The water in such a well is disturbed much more frequently than in gardens cultivated by only one farmer making it a less attractive breeding site for *Anopheles*. This might also explain why areas with a high crop diversity have relatively high odds of *Anopheles* larvae in the wet season. These generally large areas require less irrigation in the wet season as compared to the dry season, which probably results in less frequent use of the wells. Therefore, the garden size might at the same time reflect an impact of the number of farmers using it.

Some crops are known to be associated with *Anopheles* proliferation, irrigated rice in particular (Dolo et al. 2004, Dossou-yovo et al. 1994, Mboera et al. 2007, Sogoba et al. 2007). The results of this study probably underestimate the impact of rice cultivation for two reasons. First, the UA survey was mostly conducted during the dry season, when most of the numerous and large rice fields in Dar es Salaam are lying fallow, resulting in a sample size of rice fields (n = 5) too small to show any significant correlation. Second, almost all large rice growing areas had to be excluded from the study due to reasons explained in the material and methods section; therefore their impact during the wet season could not be measured. Cereals have been discussed by other authors regarding pollen of a certain variety of maize as a nutrition basis for larvae (Ye-Ebiyo et al. 2003) and in terms of increased malaria incidence (Kebede et al. 2005). Although there is a common belief that malaria vector mosquitoes breed in the leaf axils of maize plants, it has been shown that they do not (Birley & Lock 1998). The only link our study could establish was that presence of cereals in a garden resulted in a reduced probability of finding pupae. This was also seen with respect to leafy vegetables, leguminous crops and fruit. The reason behind may be the clean environment that especially larger gardens often imply. Raised beds are often planted with root crops such as sweet potatoes in Dar es Salaam and have been suspected of being important *Anopheles* breeding sites as mentioned above (Castro et al. 2004). In this study, however, root crops did not influence the probability of finding *Anopheles* larvae. Sweet potatoes were planted in raised beds in 70% of the cases. Sugar cane cultivation and presence of larvae as well as pupae were positively correlated, presumably because of the high water requirements of this crop. However, another study in Tanzania found that irrigated sugar cane production does not have any negative impact (Ijumba et al. 2002). Where leafy vegetables and larvae were both found in one place, this was mostly due to the presence of wells ensuring regular irrigation of these crops. Leafy vegetables irrigated with tap water or which are directly rainfed were rarely related to habitats.

Leguminous crops, and to some extent fruit trees, were negatively related to larval presence. The cultivation of leguminous crops such as cowpeas may therefore be an indicator for dry areas that are unlikely to contain breeding sites. In the case of fruit trees, the shade provided by their leafy canopies might even be a factor reducing the suitability of water bodies as *Anopheles* breeding sites.

In summing up the findings above, it should be stated that the characteristics of gardens with high odds of containing *Anopheles* larvae comprised the following: a location in lowland areas, proximity to rivers or ponds, loamy or clayey soils, sunken beds, sizes between 100-400 m^2 (and therefore only one user), wells, and with regard to crops, the cultivation of sugar cane or leafy vegetables. Urban gardens with relatively low odds of containing *Anopheles* breeding sites were characterised by an upland location (unless there is a lack of runoff), sandy soils, informal and planned settlements, large distance to rivers and ponds, absence of wells, irrigation by tap water or rainfed production, no specific seedbeds, very small or very large size (unless there are rice fields in the wet season) and cultivation of leguminous crops or fruit trees.

The identified characteristics of gardens with the highest potential to host *Anopheles* breeding sites bear important implications for malaria control. Their features make it relatively easy to identify and access them. The majority of gardens possessed few of these characteristics, and many had none of them at all. An integrated vector control programme could consider two strategies. First, farmers could be trained and actively involved in environmental vector control (Mboera et al. 2007, Mlozi et al. 2006, Sawio 1998), for example by establishing farmer field schools (van den Berg & Knols 2006, van den Berg et al. 2007) targeting farmers in agro-ecosystems most at risk of anopheline breeding. Agricultural extension services might play an important role in this respect, for example by promoting locally tailored environmental management practices such as planting of fruit trees as an additional crop to provide shade over water bodies (Rafatjah 1988, Walker & Lynch 2007, WHO 1982) and by combining agriculture and forestry (agroforestry) in general (Swallow & Ochola 2006). Shading wells could potentially eliminate this important *Anopheles* breeding site. Second, when needed, systematic larviciding should be used and targeted to productive habitats, particularly where environmental management practices cannot be applied.

7.6 Conclusions

Although there is an increased probability of finding *Anopheles* larvae in agricultural sites, breeding sites originated by UA account for less than 20% of all breeding sites of malaria vectors in Dar es Salaam in terms of their total number. UA thus is not the main reason for the presence of breeding *Anopheles* larvae and therefore malaria transmission in Dar es Salaam. Nevertheless, agriculture-related breeding habitats do have a high presence of larvae, and therefore represent a potential malaria risk factor that thoroughly needs to be considered by vector control programmes. Strategies comprising an integrated malaria control effort in malaria-endemic African cities may include involvement of farmers by planting shading trees near larval habitats.

7.7 Ethical considerations

This study did not involve human subjects. Research clearance was obtained from the Medical Research Coordination Committee of the National Institute for Medical Research in Tanzania (NIMR/HQ/R.8a/Vol. IX/279) and the Tanzanian Commission of Science and Technology (No. 2005-123-NA-2004-163 and No. 2006-115-ER-2004-163). This manuscript is published with kind permission of the Director of the National Institute for Medical Research of Tanzania, Dr Andrew Kitua. In order to achieve community consent and before starting any field work, the stakeholders and community leaders at the respective local government units were contacted. The goals of the activity were explained, and the survey team was introduced. All responsible UMCP staff members were present in such meetings.

7.8 Authors' contributions

SD designed and implemented the study, analysed the results and drafted the manuscript. DN, KK, DM, HM, UF, AWD, MT and GFK participated in designing and implementing the study. LG guided the modelling and statistical analyses, and assisted in drafting the respective chapters. MT and MCC had the initial idea for the study. MCC supported its design and implementation, and assisted in data analysis. All authors read and approved the final manuscript.

7.9 Acknowledgements

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8 BUILDING MULTI-LEVEL RESILIENCE IN A MALARIA CONTROL PROGRAMME IN DAR ES SALAAM, TANZANIA

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8.1 Abstract

This study applied the Multi-layered Social Resilience framework in the context of an Urban Malaria Control Programme by using a qualitative approach. It was found that exchange between and within administrative levels supported resilience-building processes in terms of mosquito breeding site elimination. “Reactive” and “proactive” capacities were successfully built among programme staff. However, more potential could be tapped among local leaders and household members, by increasing their competence in eliminating breeding sites of malaria vectors. Improving the communication skills of the programme's field workers might support such processes. Together with local leaders, they could act as multipliers of sensitisation messages.

8.2 Introduction

Malaria is a disease caused by a parasite that is transmitted through the bite of female *Anopheles* mosquitoes, and accounts for nearly one million deaths worldwide each year, mainly in sub-Saharan Africa (Hay et al. 2005, Snow et al. 2005, WHO 2008). Although much less pronounced than in rural areas (Robert et al. 2003), malaria transmission in urban settings such as the city of Dar es Salaam, Tanzania, is a significant threat to the health of the inhabitants (Donnelly et al. 2005, Hay et al. 2005, Keiser et al. 2004, Trape et al. 1993).

Only 1% of the mosquitoes in Dar es Salaam are *Anopheles* (Fillinger et al. 2008). All other mosquito species are not able to transmit malaria, but are responsible for other diseases such as lymphatic filariasis, and may pose a tremendous nuisance. Although *Anopheles* larvae typically breed in relatively clean, shallow and sunlit standing water that can be found for example in puddles and rice fields, they can also be encountered in heavily polluted water bodies such as blocked sewage drains or pit latrines (Sattler et al. 2005).

Dar es Salaam has a long history of malaria control, starting more than 100 years ago in the German colonial era (Castro et al. 2004, Mukabana et al. 2006). Today, one of the pillars of the Tanzanian National Malaria Control Programme (Tanzanian Ministry of Health & World Health Organization 2004) is vector control, mainly by promoting the use of insecticide-treated bednets (Magesa et al. 2005), but also by targeting mosquitoes in their larval stage. In

Dar es Salaam, the latter intervention is implemented by the Urban Malaria Control Programme (UMCP), which is integrated on all administrative levels of the city (Fillinger et al. 2008). The UMCP builds on experiences and structures that result from earlier and existing programmes aiming at vector control to improve urban health in general, by adding a larval control component. The main aim of the UMCP is to reduce the level of malaria infection prevalence by community-based elimination of breeding sites for *Anopheles* larvae.

The underlying theoretical framework for this multi-level study is the 'Multi-layered Social Resilience' framework by Obrist et al. (2010b). For the first time, this framework conceptualises resilience in a way that makes it applicable in the field of development studies. Adapting the definition of Obrist et al. (2010b) to the context of this study, social resilience relates to "social actors' capacities to not only cope with and adjust to malaria threat ("reactive" capacities), but search for and create options ("proactive" capacities)", and thus develop increased competence in mitigating malaria threat by eliminating mosquito breeding sites in Dar es Salaam, with the positive outcome of not getting ill with malaria (Figure 8.1).

The Multi-layered Social Resilience framework draws on ecological (Carpenter et al. 2001, Folke et al. 2002, Holling 1973), psychological (Luthar 2003, Masten 2001) and socio-anthropological approaches (Bourdieu 1984, 1986), as well as DfID's Sustainable Livelihood approach (DFID 2000). Resilience is implicit in the Sustainable Livelihood approach (Obrist et al. 2010b), because "rather than focusing on barriers to sustainable development, it draws attention on people's capabilities, assets and activities leading to positive outcomes". Two features of the new concept are particularly important: First, social and economic capital, and notably also cultural and symbolic capital (Bourdieu 1984, 1986, DFID 2000) play an important role in resilience building processes. Second, that resilience is multi-layered, ranging from the individual, household to the community, national and even global level. Sustainable livelihood systems consist of 'layers of resilience', including multi-level networks that enable people to overcome 'waves of adversity' which may be experienced when changing circumstances, for example seasonal peaks in disease transmission, meet reduced adaptive capacity (Glavovic et al. 2003). The ability to cope with change is influenced by networks that enable people to access resources, learn from experience and develop constructive ways of dealing with common problems. Therefore, the mobilisation of networks can contribute to building 'layers of resilience'. Important resources, such as knowledge and information, can be accessed and built up through existing networks relevant to a specific threat. These networks are often comprised of various levels (individual, intermediate and national levels) (Figure 8.1). Exchange between the different levels can contribute to resilience building and increased competence. In line with the multi-level nature of the UMCP (intermediate levels: UMCP staff and local leaders; individual levels: household members) (Figure 8.2) and drawing on the Multi-layered Social Resilience framework, our study investigates the multi-level character of resilience in the context of the UMCP. The role of the capitals mentioned above was not subject of this study, but was explored in a rural setting in Tanzania by Obrist et al. (2010a).

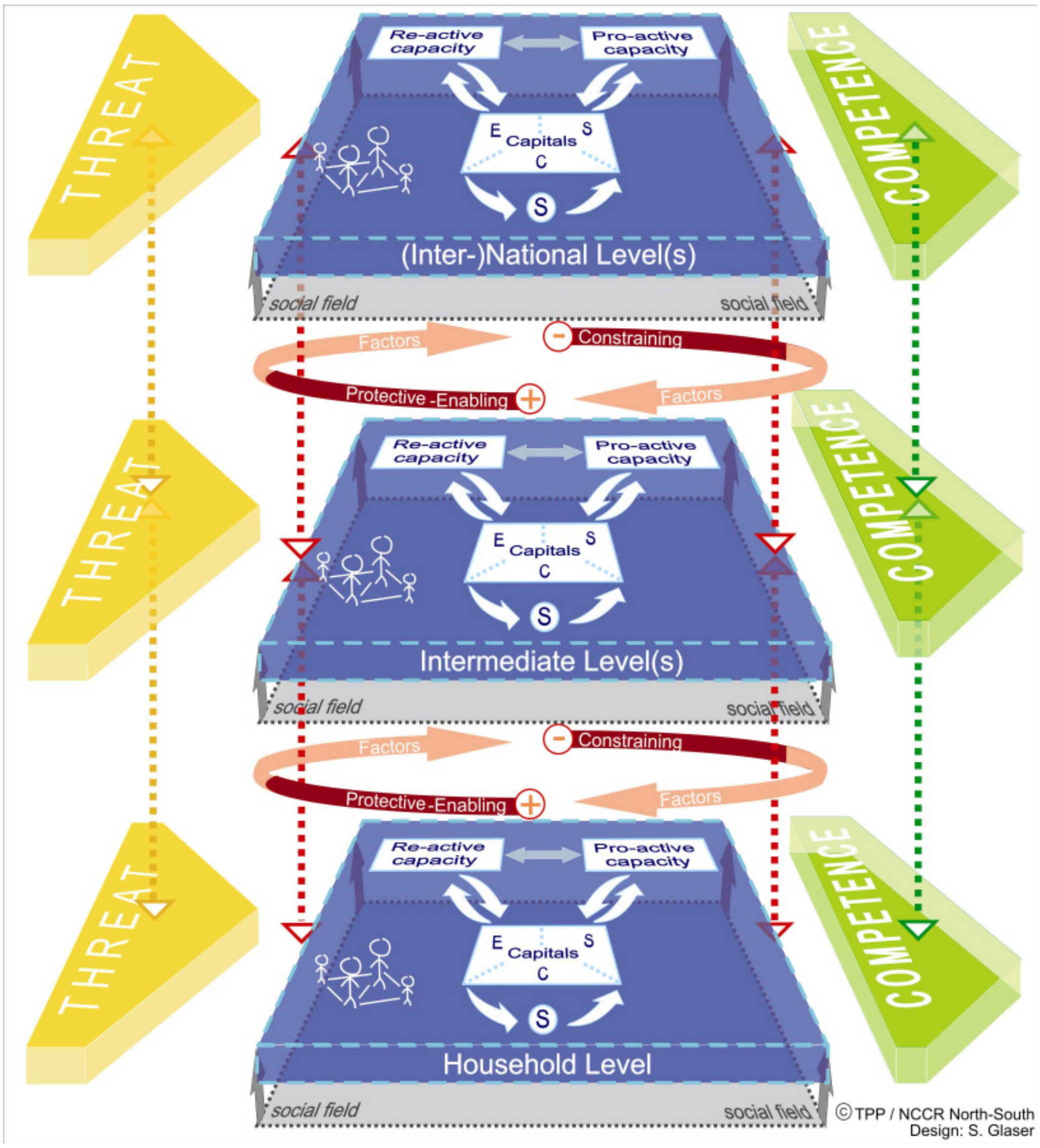

Figure 8.1: Multi-layered Social Resilience framework

Source: Obrist et al. (2010b)

The Multi-layered Social Resilience framework is a strength-based approach. We consider this useful in our context because it invokes a positive perspective that draws attention to the ability of people to positively adjust to malaria risk. These questions have so far been neglected in the public health and social development literature, as well as in the social science literature. Most research has been guided by a deficit approach emphasising risk and vulnerability. Resilience thinking can provide policy-makers and researchers a different, notably solution-oriented way of thinking about populations at risk (Obrist et al. 2010b).

The aim of this study was to examine whether the UMCP managed to increase “reactive” as well as “proactive” capacities, in terms of breeding site elimination not only of UMCP staff who received training in this respect, but also of local leaders and household members on individual and intermediate levels (Figure 8.2) who were not directly targeted. The strengthening of these capacities may enable the above mentioned actors to access resources in terms of knowledge and information, and to increase their own scopes of action with regard to mitigating the threat of *Anopheles* breeding sites. If not eliminated, the resulting mosquitoes may cause an increase in malaria transmission leading to severe health problems.

The discussion of the results is guided by the Multi-layered Social Resilience framework, which identifies “reactive” capacities (coping with and adjusting to malaria threat by eliminating breeding sites), “proactive” capacities (searching for and creating options to eliminate breeding sites), and enabling factors such as the working environment, while distinguishing between UMCP staff, local leaders, and household members.

We argue that while the UMCP managed to establish “reactive” and “proactive” capacities of staff on all intermediate levels of the UMCP staff, there is untapped potential among the intermediate levels of local leaders, and particularly among household members on the individual level. One possible way to overcome this gap and optimise resilience-building processes for everyone may be through improving the communication skills of UMCP field staff.

8.3 The local context

Dar es Salaam is the largest city of Tanzania with a population of almost three million people in 2007 (UN 2008b). As study areas, we chose three wards of Dar es Salaam, namely

Mikocheni, Buguruni and Kurasini. These wards are located at a distance of 1-10km from the city centre, and have a total of 128,000 inhabitants (National Bureau of Statistics 2003). The study wards were chosen purposefully, as they were the first wards in which the UMCP started its larviciding intervention in March 2006 (Fillinger et al. 2008). At present, the UMCP is in the process of being scaled up to an area comprising two million inhabitants.

All UMCP activities are fully integrated into the decentralised administrative system in Dar es Salaam (Figure 8.2). The UMCP operates on all administrative levels: city level (city council), municipalities, wards, neighbourhoods (*mitaa* in Kiswahili, meaning literally street), and ten-cell-units (TCUs, the smallest administrative units, typically comprising about ten houses, with an elected leader). We refer to the entity of these levels as the intermediate levels, whereas household members belong to the individual level.

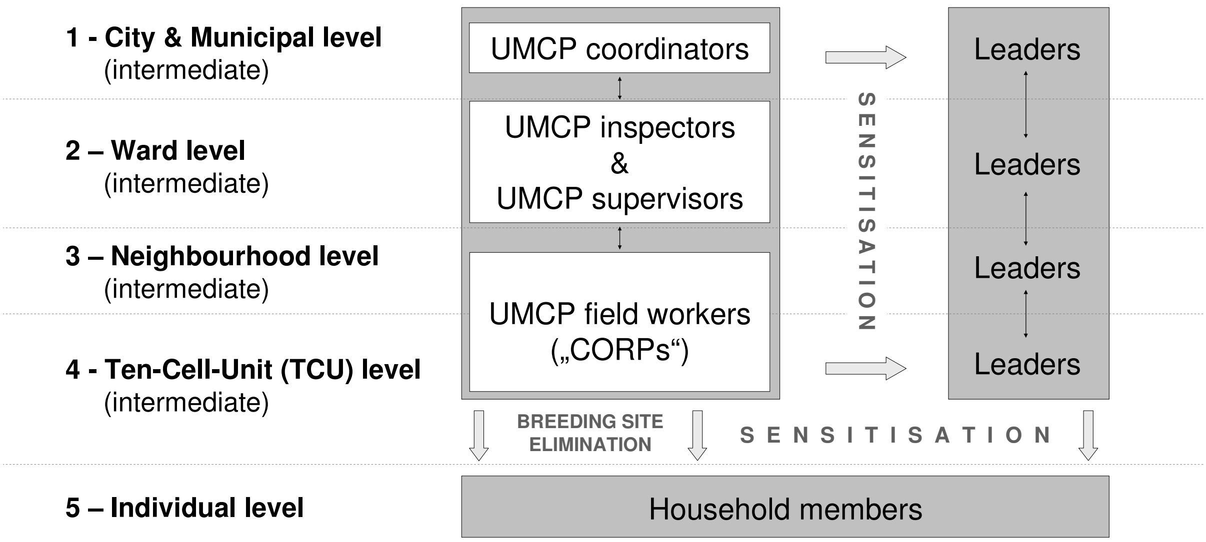

Figure 8.2: UMCP multi-level organisational structure

UMCP staff members on all levels were trained according to their respective tasks. The main tasks on the city, municipal, ward and neighbourhood levels are project management and supervision. Actual mosquito larval control – the core activity of the UMCP – is implemented on TCU level by community-owned resource persons (CORPs) that play a key role in the programme (Castro et al. 2004, Fillinger et al. 2008, Mukabana et al. 2006). The CORPs are volunteers receiving a small remuneration of cash (i.e., USD 2.50 per working day), and are usually members of the community they are working in. They are wearing T-Shirts identifying them as UMCP staff members. CORPs are appointed and managed through local administrative leaders on the neighbourhood level. One group of CORPs is responsible for larval surveillance, in terms of monitoring and documenting the larval habitats of mosquitoes in every TCU in weekly intervals. The other group of CORPs is responsible for applying biological larvicide (*Bacillus thuringiensis* var. *israelensis*, BTI) where necessary, on the day after the visit of the surveillance CORPs. All CORPs are working mostly in the field, going from house to house in every TCU (Fillinger et al. 2008, Mukabana et al. 2006, Vanek et al. 2006).

Another central task for UMCP staff on each level (including the CORPs) is sensitisation of community members to the project. In theory, this is comprised of information about the work of UMCP, on how to remove breeding sites for mosquito larvae, and on how to prevent their creation in the first place. In practice, however, the UMCP was forced to prioritise other activities due to limited time and funds. As a consequence, the sensitisation activities carried out in the communities were only intended to gain community consent. Sensitisation methods include meetings with community leaders, public meetings with the community, cars with megaphones passing through the intervention areas, and distribution of leaflets. For more detailed information about the UMCP and the respective tasks of staff see Fillinger et al. (2008).

8.4 Methods

This study is using a qualitative approach. After developing the interview guidelines, the field work was carried out in September 2006, six months after the commencement of the UMCP larviciding intervention. In total, 29 semi-structured key informant interviews and 11 focus group discussions (FGDs) were conducted. Figure 8.3 shows the respective functions, numbers, levels and wards of the respondents. The respondents of the key informant interviews were chosen purposefully according to their function. UMCP staff interviewed in each of the three wards included municipal malaria coordinators (municipal level), inspectors, supervisors (ward level), and CORPs (neighbourhood and TCU level). Further interviews were conducted with local leaders indirectly related to the UMCP in each ward. These comprised agricultural and livestock officers, representatives of the health and environment committees, water & sanitation committees (municipal, ward and neighbourhood level), and

TCU leaders (TCU level). The participants of the FGDs (individual level) were selected by their respective TCU leaders, from TCUs that were chosen purposefully according to their locations. Five groups consisted of women aged 20-65 years old, and six groups consisted of men aged 20-56 years. All respondents that were not already on the payroll of the UMCP received soap bars as an incentive.

The field team consisted of eight Tanzanians. Two senior team members supervised and coordinated the remaining six team members that were all trained and experienced in qualitative field methods. These were divided into three groups of two, mixed male and female, with each group facilitating the interviews and FGDs within one ward. All interviews and FGDs were held in Swahili, and recorded on tape. The interviews with UMCP staff members took place in or near their offices, while some of the local leaders were interviewed at their homes. FGDs took place at convenient venues close to the homes of the participants. Each interview/FGD took about one hour. One facilitator acted as moderator of the activity, while the other one was responsible for taking notes and later producing a hand-written transcription. The Swahili transcriptions were then translated into English by the facilitators. The hand-written English transcriptions were typed and saved as documents in rich text format. Content analysis of the typed English transcriptions was done in MAXQDA [VERBI Software, Marburg, Germany].

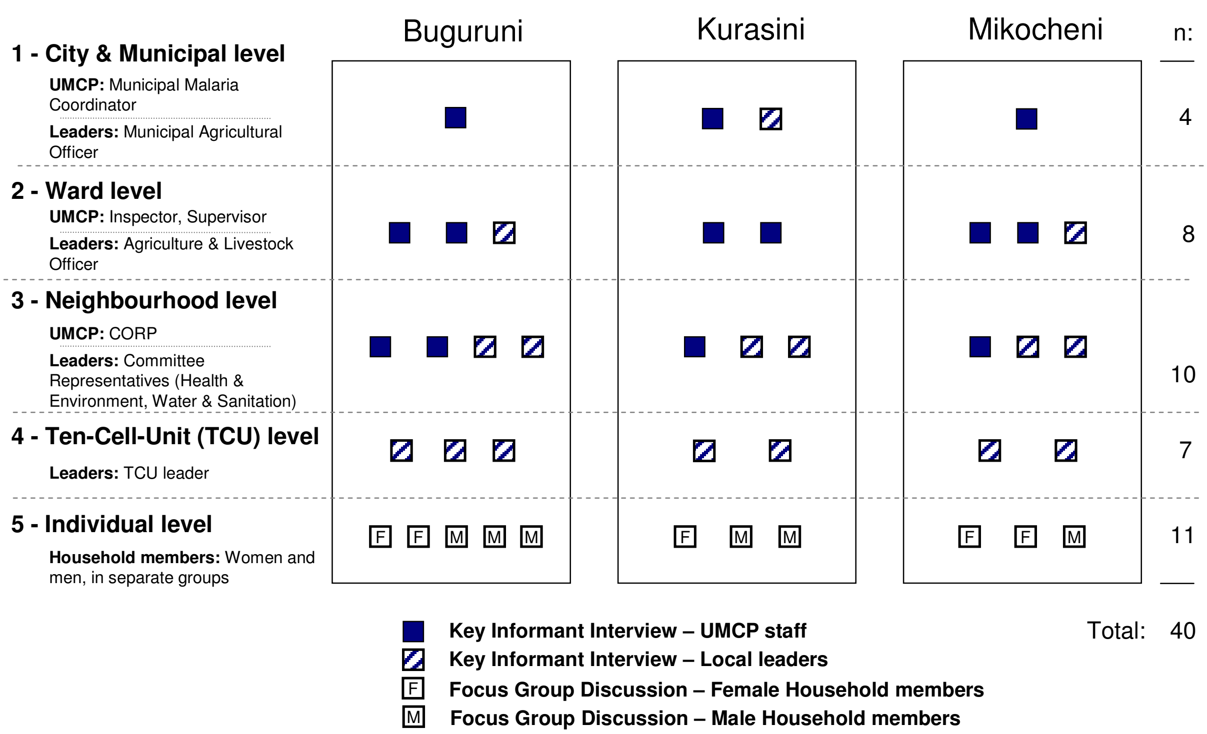

Figure 8.3: Respondents and levels of interviews and FGDs

8.5 Findings

Building on the Multi-layered Social Resilience framework of Obrist et al. (2010b), we present factors related to resilience building processes that lead to enhanced competence in eliminating breeding sites in the context of the UMCP. For this purpose, we describe “reactive” capacities and “proactive” capacities that social actors gained through the UMCP, combined with enabling factors supporting this process. Distinctions are made regarding the individual and intermediate levels. For simplification, respondents on the intermediate levels are grouped into “UMCP staff” and “local leaders”, whereas respondents on the individual level are referred to as “household members” (Figure 8.2). Local leaders and household members are only indirectly involved in the UMCP.

Coping and adjusting to malaria threat (“reactive” capacities)

The most important “reactive” capacity that helps to increase competence in eliminating malaria vector breeding sites is having the ability to identify such breeding sites, to prevent their creation, and to eliminate existing ones. We found that all UMCP staff members had the capacity to correctly explain in detail the characteristics of breeding sites that are suitable for *Anopheles* larvae. Most importantly, all staff members were involved in breeding site elimination, either directly in the field or by managing and supervising this process.

> *“What we are doing now is identifying the mosquito breeding sites and putting larvicide there to kill mosquito larvae” (UMCP Supervisor, ward level)*

> *“Apart from administering activities, I make follow-ups to make sure every mosquito breeding site is known and treated. Our main intention is to make sure that mosquitoes disappear completely in Kurasini.” (UMCP Supervisor, ward level)*

Having the correct knowledge in order to cope and adjust to malaria threat caused by mosquito breeding sites is seen as part of the ability to effectively eliminate them.

“You can find people who don’t understand these issues, and for them to change, they need to be educated first.” (Woman, Buguruni[24], individual level)

“Without knowledge, it is difficult to motivate people to maintain cleanliness” (Woman, Buguruni, individual level)

“People who are knowledgeable keep their environment clean.” (Man, Buguruni, individual level)

The majority of local leaders stated that they were involved in breeding site elimination, either by urging their fellow citizens to prevent and remove standing water, or by actively removing such sites themselves. All of them were able to name one or more potential *Anopheles* breeding sites. However, rubbish was often mistakenly referred to as a source of malaria-transmitting mosquitoes, and half of the leaders stated that measures like removing tall grass or bushes around houses would eliminate breeding sites. These incorrect assumptions were already observed in the 1990s (Stephens et al. 1995) and are also found elsewhere, for example in rural Kenya (Opiyo et al. 2007).

“We fill up those ponds and furrows around our houses and open these streams so that water may move.” (TCU leader, Buguruni, TCU level)

“Apart from general cleanliness, we have to control toilets that cause flowing water (wastewater) near our environment. We need to control the dumping […] of rubbish in our surroundings. This would prevent mosquitoes from finding breeding sites.” (Health Committee Representative, neighbourhood level)

In most groups of household members, at least one potential *Anopheles* breeding site was mentioned. Respondents in the majority of the focus groups stated that they actively ensured cleanliness. The notion of cleanliness encompasses cleaning and unblocking drains, avoiding water flowing openly from bathrooms or toilets, removing or burning garbage, as well as removing tall grass, bushes, garbage, standing water on the ground, and containers that hold water. While some of these actions might indeed reduce mosquito breeding sites in general, most of them will not. Many *Anopheles* breeding sites such as burrow pits, puddles, irrigated

[24] The location is only included where it does not allow conclusions about the identity of the respondent

agricultural sites and swampy areas are not affected by such measures. Similar to the local leaders, some household members suggested actions such as the removal of tall grass and bushes that don’t have any effect on reducing breeding sites at all.

> *“Without garbage, mosquitoes can’t breed” (Man, Buguruni, individual level)*

> *“The main cause for malaria is these ponds containing dirty water in conjunction with a lot of garbage which is lying around everywhere.” (Man, Buguruni, individual level)*

> *“We […] maintain cleanliness around our compound to make sure that there are no mosquito breeding sites.” (Woman, Buguruni, individual level)*

Summing up the above findings, most of the respondents stated that they were preventing and removing mosquito breeding sites. However, the mentioned activities were only partly suitable for the purpose of eliminating *Anopheles* breeding sites. In comparison of the different group’s competencies, regarding breeding site elimination resulting from coping and adjusting to the related threat, a “knowledge gap” between the three groups of social actors became apparent. This gap separated the individual level from the intermediate levels, and also occurred within the intermediate levels between UMCP staff and local leaders. On the one hand, the correct and relevant knowledge of UMCP staff corresponded with active and targeted involvement in breeding site elimination. On the other hand, the rather diffuse and sometimes incorrect knowledge of local leaders and household members was more likely to impair their competence in dealing with malaria vector breeding sites.

The main enabling factors that supported building this competence were the work-related trainings for UMCP staff, and sensitisation of local leaders and household members by UMCP staff[25]. The UMCP itself is a crucial enabling factor in this regard as staff were trained in order to have the technical knowledge – but not necessarily the communication skills – needed to sensitise leaders and household members. By receiving training, UMCP staff benefited considerably in that they gained relevant and correct capacities. About half of the staff members said they learned through their work.

[25] In the context of this study, „training“ refers to training that UMCP staff receives in the frame of their work. “Sensitisation” refers to sensitisation in terms of knowledge and information about the work of UMCP and possibilities of breeding site elimination, provided to household members and local leaders, for example by UMCP staff.

> *"I am employed in this project (UMCP). I learnt a lot of things about malaria and what I can do in order to protect myself and my family against malaria." (UMCP Supervisor, ward level)*

Community sensitisation in general can have a very big impact on individual behaviour and in building competence. This is shown by the fact that all respondents on the intermediate levels, and most household members, stated that they knew how malaria is transmitted and that they used mosquito nets to protect themselves against malaria. The most important enabling factors mentioned in this respect were the media, mainly TV, radio and newspapers, but also hospitals which provided relevant information. The use of insecticide-treated bednets, for example, has been promoted by a national programme since 2000 (Magesa et al. 2005). This knowledge increases the capacities to cope and adapt to malaria threat by providing additional control options.

The majority of local leaders stated that they received sensitisation about the work of UMCP and breeding sites of malaria vectors, and that they also sensitised others, usually their community members. Some household members said that they received information about the larvicide used by UMCP. The majority of non-UMCP respondents stated they felt an impact of UMCP efforts, in terms of reduced mosquito density since the programme had started.

> *"Mosquitoes have decreased drastically since this project started." (Man, Kurasini, individual level)*

The "knowledge gap" mentioned above is thus due to a "sensitisation gap" which is most pronounced between the individual level and all higher levels. Another yet smaller "sensitisation gap" exists within the intermediate levels, between UMCP staff and local leaders. All respondents, including UMCP staff, stated that household members and also local leaders needed more knowledge in terms of breeding site elimination, cleanliness and malaria in general, and that sensitisation was the key activity to achieve this. Although sensitisation in this respect was not the mandate of the UMCP, it was seen to have considerable potential for closing the gaps.

“What is needed is to educate or sensitise the community to change their behaviour and attitude, because all the breeding sites such as drains and ponds are found near their places. So if they decide to say that from today on we don’t want malaria, it will disappear. Let them clean drains and furrows, fill in the pit holes and remove empty tins, I think they will reduce the problem of malaria.” (UMCP Malaria Coordinator, municipal level)

“The most important thing now for us is to sensitise people about environmental sanitation and cleanliness. To make sure that water does not stand in their areas.” (Health Committee Representative, neighbourhood level)

“Another thing that can be done is to provide enough education to the people about the whole issue of malaria, because other people don’t understand where mosquitoes breed and how they can control malaria.” (Man, Buguruni, individual level)

The majority of local leaders stated that they play an active role in sensitisation activities. However, the delivered messages were not always in line with the UMCP activities.

“As a leader you can go somewhere and talk with some people (key ones) whom you think that they can send the message to the rest. […] I sensitize my people to carry out environmental cleanness.” (Agricultural Officer, ward level)

The potential future role of the CORPs regarding more and better sensitisation was discussed and reflected by respondents, on all levels and from all groups. At the same time, it was noted that this cannot be realised without specific training, including improving communication skills.

“They should inform people about how and where mosquitoes breed. Spraying insecticides and leaving without communication doesn’t help.” (Man, Kurasini, individual level)

“I would like to ask that the staff of the project needs to be given more training. For their activities they could be given something like seminars so that they get enough

knowledge and are able to pass it on to the community." (Man, Buguruni, individual level)

"Community members […] are not always involved by us (UMCP staff)" (UMCP Inspector, ward level)

"What we are supposed to do is to provide enough education to these CORPs so that they will help us to educate the community members, and this will help a lot to control malaria." (UMCP Malaria Coordinator, municipal level)

Searching for and creating options to eliminate breeding sites ("proactive" capacities)

"Proactive" capacities were mentioned a lot less frequently than "reactive" ones, and notably only by some UMCP staff and local leaders, but not by household members. UMCP members searched for and created options to improve breeding site elimination in the frame of the programme itself. On higher staff levels, learning from past experiences was seen to positively impact programme success, such as preferring to work with experienced staff as opposed to newcomers.

"Taking CORPs who were working with UNICEF made supervision very easy. If I had taken inexperienced people, they could have left after two days and would have left me alone. They could even have stolen work tools. These CORPs are experienced and they are well-known all the way up to the Municipal Council." (UMCP Malaria Coordinator, municipal level)

On the lower staff levels, one CORP found a creative solution to improve orientation in difficult environments:

"Sometimes, I forget if some of the sites were new or old ones. […] we put some marks like sticks with nylon bags, so that when I go there, I know which site is new or old." (CORP, neighbourhood level)

On an individual basis, “proactive” behaviour was reported from one UMCP staff member who considered it important to share his knowledge, not only in the frame of his daily work routine, but also within his family. However, this knowledge had not been gained from the UMCP, but from other enabling factors such as school education or governmental campaigns.

> *“I need to sensitize the family members not to throw rubbish just anyhow, because they can throw them in places where they can cause mosquito breeding to take place.” (UMCP supervisor, ward level)*

Some local leaders acted “proactively”, too. Whereas some TCU leaders created options for actively removing breeding sites themselves, without waiting for others to do the job, some committee representatives reported that their committees searched for and came up with solutions for team efforts that supported the activities of others.

> *“I called a meeting, we collected some money from our own pockets, we bought some tools and started cleaning the environment, including opening the blocked streams and furrows so that water could pass smoothly.” (TCU leader, Buguruni, TCU level)*

> *“In our ward meetings, we share the challenges we meet in our work. We also brainstorm and plan how to assist the people of the malaria project (UMCP) so that they can be able to work more smoothly.” (Agriculture and Livestock Officer, ward level)*

On the part of household members, no one mentioned being involved in searching for or creating options that contribute to breeding sites elimination. At the same time, respondents on the intermediate levels repeatedly described Dar es Salaam’s residents as somewhat passive, and with having a tendency to shift responsibility on to higher levels. Phrases like “the government should do…” or “the government should provide…” appeared in the majority of discussions with household members, but only in very few interviews with leaders and staff members.

> *“The government should give us dawa (larvicide) to spray in the gardens in order to remove breeding sites.” (Woman, Buguruni, individual level)*

"Here, there is a problem to the people: You know, we always depend on the government to do everything for us. We always wait for the government or other institutions to come and clean our environment or help us to control malaria. We don't have our own efforts to try to control malaria." (TCU leader, Buguruni, TCU level)

"Us Tanzanians, most of us have the tendency to wait for someone to do follow-up. We expect to get everything from top levels." (Agricultural Officer, ward level)

At the same time, half of the leaders and household members in about half of the groups stated that they "proactively" approached UMCP staff in order to find out about the intention of their work. Nevertheless, many respondents never attempted to ask them anything.

"When they pass around, they go on with their activities and we continue with ours." (Man, Kurasini, individual level)

Some respondents considered close supervision and constant repetition of sensitisation activities and messages to be crucial for reaching and sustaining active involvement of household members.

"Even in the classroom a teacher has to teach more than once before a student can understand. So the same applies to us, if they keep on telling us consistently we shall understand." (Woman, Mikocheni, individual level)

"If leaders are quiet, citizens will forget about their responsibilities" (Man, Kurasini, individual level)

8.6 Discussion and conclusion

All UMCP staff members had the "reactive" capacity to correctly explain characteristics of *Anopheles* breeding sites, combined with active involvement in the elimination of such breeding sites. While a considerable part of the household members and local leaders on all levels stated that they were also actively involved in breeding site elimination, there was a "knowledge gap" separating UMCP staff from local leaders and household members. This "knowledge gap" appears to be due to a "sensitisation gap" that prevented the individual level from gaining breeding site elimination know-how available on higher levels. The "sensitisation gap" also partly prevented local leaders from gaining breeding site elimination know-how from UMCP staff (i.e., within intermediate levels). Similarly, "proactive" capacities could only be attributed to some UMCP staff and local leaders, but not to household members.

The relatively high capacity level of UMCP staff in terms of coping and adjusting to threat related to breeding sites is likely to be the result of several factors. First, the project structure having a central management team at the city level, with decentralised delegation of managerial and supervisory responsibilities to the municipal and ward levels, and with fieldwork on the neighbourhood and TCU levels seemed to function well. Second, the preparatory phase of the UMCP that already started two years before actual larviciding began appears to have been long enough for recruiting and training staff, and for establishing, practicing and readjusting routine work procedures. Learning from experience, as well as having enough time, appears to have contributed to competence building. Third, the training materials which had been prepared in a participatory manner and refined through early field piloting (Fillinger et al. 2008) seem to have been appropriate, and the trainings conducted in a way that effectively imparted knowledge to all staff levels.

The UMCP theoretically provides for a range of sensitisation tasks on all levels, comprised of internal staff training related to sensitisation, but also actual community sensitisation (Fillinger et al. 2008). The partial lack of "reactive" capacities regarding local leaders and the comparably large deficits on the individual level indeed indicate that sensitisation activities from the side of UMCP have not sufficiently targeted these groups. This can be attributed to the fact that in the first months and years, the UMCP had to concentrate on reducing the number of mosquitoes in order to justify and secure continued external funding. As a consequence, the UMCP could not spend more than 5% of the programme's time and funds on sensitisation activities. The latter aimed at gaining community consent, not at training household members in breeding site elimination (K. Kannady, personal communication). Reduction of malaria transmission needed to be achieved as fast as possible and was therefore prioritised over public education efforts (U. Fillinger, personal communication). In the two years following the field work for this study, considerably more time and effort has been invested in sensitisation, for example by broadcasting TV spots about the work of the UMCP

(K. Kannady, personal communication). However, it needs to be taken into account that local leaders on any level might be driven by other agendas than only the well being of their community.

We agree with Obrist et al. (2010b) that resilience-building processes also depend on factors related to the national level, for example via ongoing bednet promotion campaigns that positively influenced the work of the UMCP. The fact that almost all respondents knew that malaria is transmitted by mosquito bites probably facilitated the work of the UMCP considerably, as the malaria-reducing effect of larviciding is likely to appear rather evident to someone availing of this knowledge. The potential impact of this campaign on the national level can also be illustrated by the fact that almost all respondents stated they used bednets as means of protection against malaria. Bednet use in general has increased significantly during the past decade, following continuous promotion by the Tanzanian National Malaria Control Programme (Magesa et al. 2005). The related knowledge has therefore trickled down through all levels. This confirms former findings made by the UMCP: "An important lesson of the [former UMCP] program is that government has a crucial role in promoting awareness of the problems, and pointing to alternatives for preventing and solving them. Through this mechanism, community cooperation and involvement may be achieved successfully" (Castro et al. 2004). Similarly, based on findings in rural Kenya, Opiyo et al. (2007) point out the "vital role of NGOs, central government education departments and schools in enabling communities to access appropriate information" related to breeding site elimination. Organisations on the national level, and the state in general, can therefore substantially contribute to resilience building processes on lower levels, and be a powerful enabling factor for intermediate level organisations such as the UMCP. On the individual level, these organisations can help fill the "sensitisation gap" by responding to the widely expressed need for more sensitisation, which may be caused by the limited scope of action and restricted information resources within the respective networks of household members.

A network of social actors enables people to access resources such as information on breeding sites of malaria vectors (Glavovic et al. 2003). The UMCP, including all directly and indirectly involved actors, is an example for such an exchange and use of such a network. It can serve as "glue" that binds together people, enabling them to work together on the common challenge of eliminating *Anopheles* breeding sites, and therefore mitigating malaria threat (Glavovic et al. 2003). However, although the UMCP is a strong organisation, the lack of exchange between the intermediate and the individual level prevents the UMCP from making a bigger difference to the pools of resources available to the household members, particularly via providing information that increases skills and abilities. Although to less extent, a potential for more exchange can also be observed within the intermediate levels, for UMCP staff and local leaders on ward, neighbourhood and TCU level. We therefore concur with the claim made by Obrist et al. (2010b) that increased attention should be given to the exchange both within and between the different levels.

From the perspective of Obrist et al. (2010b), the UMCP contributed to enhancing competence by strengthening “layers of resilience” (Glavovic et al. 2003): On the one hand, individuals, namely staff members and some of the local leaders, built resilience by learning technical skills to cope with and even prevent the threat caused by *Anopheles* breeding sites. On the other hand, being an organisation that links all levels, the UMCP steadily strengthened its own resilience by continuous training of staff. ‘Thickening’ this “layer of resilience” (Glavovic et al. 2003) by adding more emphasis to training of communication skills would in turn also strengthen the first layer, as more individuals would become part of it and benefit from it.

“Proactive” capacities were relatively rarely mentioned. This is normal to some extent, as building such capacities takes a lot longer than simply transferring knowledge. Nevertheless, it is striking that some UMCP staff members and local leaders were indeed searching for and creating options, but apparently none of the household members were. A reason for this might be that the staff members virtually “feel” the capacity they gained from their training. This might motivate them to act proactively, for example by doing their work thoroughly, or by sharing their knowledge with family members. Conversely, one might argue that household members passively noticing the ongoing larviciding activities, while not being reached by corresponding sensitisation activities, may think they lack crucial knowledge, feel excluded or frustrated, which in turn may lead to a rather passive attitude. In line with Glavovic et al. (2003), we argue that more participation is central to fostering “reactive” capacities that may eventually lead to increased “proactive” behaviour. As discussed above, this can only be the case when links between all positions and levels are established in the network of social actors.

Applying the Multi-layered Social Resilience framework for identifying "proactive" capacities merely by content analysis of our interviews and FGDs proved to be very difficult. Measuring such capacities was not possible given the short time frame of our study. For the same reason, it was not possible to explore the kind of "proactive" behaviour that social actors expected from social actors on other levels. Such analyses might shed more light on the nature of "proactive" capacities. Long-term studies as described for example by Werner and Smith (1982) appear more appropriate to measure resilience-building processes, ideally with mixed methods approaches involving participant observation.

Apart from these difficulties, the Multi-layered Social Resilience framework proved to be very useful in the context of our study. Although we did not include "assets", it was ideal for structuring our data, as well as for analysis. The necessity of narrowly defining the "threat" in the first place helped a lot in the analysis of capacities and enabling factors contributing to resilience-building processes against this threat. The multi-level approach was particularly useful in our context, as it allowed us to identify "gaps" between actors as the main finding of our study. These gaps could be found horizontally between the intermediate and the individual level, but also vertically within the intermediate levels.

In the context of this study, it was possible to directly translate the different levels of the Multi-layered Social Resilience framework to the existing administrative levels in Dar es Salaam. This ideal situation might not always be given elsewhere. In such cases, it would be necessary to apply levels referred to by the respective actors, which can also be symbolic or constructed.

A crucial future role in achieving comprehensive coverage of community sensitisation related to breeding site elimination might by played by the CORPs. They can be regarded as "development brokers", acting as intermediaries between programmes and community members, understanding the often different logics of both entities (APAD 1996, Bierschenk 1988, Elwert & Bierschenk 1988). On behalf of the UMCP, they are the ones interacting with household members individually and on a day-to-day basis. However, this interaction has so far generally been restricted to applying larvicide and ensuring access to all necessary areas. Adding training modules for the CORPs related to sensitisation messages and techniques might considerably improve capacities, thus enhancing competence on the individual level. Therefore, more effort should be put in training the communication skills of CORPs. These trainings could be comprised of teaching the ability to approach people, the ability to explain the aims of their programme, and the ability to inform household members what they can do themselves in order to eliminate mosquito-breeding sites, including those of malaria vectors. Nevertheless, in order to have the desired impact, sensitisation has to go beyond mere transfer of knowledge: it needs to initiate actual behavioural change. Furthermore, it needs to be considered that not all CORPs have the same social standing in the community, for example due to their age.

We conclude that although the UMCP managed to successfully build capacities among UMCP staff, there is a potential to increasingly involve CORPs and local leaders as multipliers of sensitisation messages, so that they can help building resilience among household members.

8.7 Acknowledgements

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9 CONCLUSIONS

The findings of this thesis emphasise that urban agriculture (UA) is a widespread land use that potentially contributes to malaria threat in Dar es Salaam. At the same time, operational malaria control in Dar es Salaam supports resilience-building processes by building capacities to mitigate this threat. Building on these results, options for improving vector control programmes were identified.

The general conclusions above were derived from results gained in four research steps, each reflecting one of the four single objectives of the thesis. First, a GIS-supported agricultural survey illustrated that UA is a widespread land use, thus contributing to the livelihoods of many farmers. More than 5% of the study area was cultivated in 2005. Comparison with data from earlier years revealed that urban farming is a dynamic, but not a short-lived or transitional phenomenon. In fact, the overall extent of UA did not decrease during the past two decades, despite the city's rapid growth and densification.

The second step was predominantly a methodological input into the study. In order to be able to link the agricultural data with routinely collected larval data of the UMCP, a participatory mapping procedure was developed. Its validation in the field established a necessary spatial reference system, which was based on the smallest administrative units in Tanzania. This mapping procedure proved to be an essential contribution towards the optimisation of UMCP operational procedures.

In a third step, this thesis confirmed that UA potentially contributes to malaria threat by providing suitable mosquito breeding sites. More than 1 in 10 agricultural areas contained habitats with larvae of *Anopheles* mosquitoes. Common breeding sites in agricultural areas were dug wells, but also other bodies of stagnant surface water. The presence of *Anopheles* larvae in urban farming areas was not only related to agricultural features such as specific seedbed types, crops and garden sizes, but also to geographical factors such as topography, hydrology and soil type. Urban farming therefore needs to be thoroughly considered by integrated vector control programmes. However, it is important to differentiate between different agricultural practices. Small gardens, rainfed production and tap water irrigation rarely created suitable breeding sites. Moreover, *Anopheles* larvae were seldom found where crops like cowpeas, pigeon peas and fruit trees were cultivated. In general, agricultural land use accounted for less than a fifth of all malaria vector breeding sites in Dar es Salaam. The role of urban farming with regard to malaria risk should therefore not be overemphasized. Farmers should instead be regarded as potential assets in vector control. For example, they could be involved by planting shade trees near water bodies in agricultural areas.

While the above studies relied on quantitative approaches, the final part of this thesis built on qualitative methods. By applying the Social Resilience Framework in the context of the UMCP, resilience-building processes on various programme levels were analysed. It was found that the UMCP successfully built capacities of UMCP stakeholders on all levels, but only partly on the household level. Improved mitigation strategies related to environmental malaria control could therefore build on increased participation of household members within the UMCP intervention area. This could be achieved by building their capacities in breeding site elimination, through enhanced sensitisation provided by UMCP field workers which are key to the programme.

The essence of these insights, gained by conducting transdisciplinary operational research, provides a basis for optimising malaria control and urban planning in Dar es Salaam, but also other malaria-affected SSA cities. Concrete recommendations for research and practice are outlined in the following sections.

9.1 Prospects for future research

What is the potential of agroforestry for malaria control in UA?

Agroforestry, an agricultural practice involving the deliberate management of trees on farms and in surrounding areas (Swallow & Ochola 2006), may be an effective vector control option in the context of Dar es Salaam UA. Shading by tree planting near potential larval habitats has been demonstrated to be useful in the control of anopheline species, and may help to reduce *Anopheles* larvae in SSA (Rafatjah 1988, Walker & Lynch 2007, WHO 1982). Furthermore, it might improve drainage in areas with standing ground water (van der Hoek 2006, Walker & Lynch 2007). Agroforestry may offer additional benefits to farmers by improving soil fertility, and providing animal fodder, fruit crops and fuel wood. Income generated from agroforestry systems is generally higher than from continuous unfertilised food crops

(Swallow & Ochola 2006). A transdisciplinary longitudinal study, planned and implemented in close co-operation with farmers, responsible Agricultural Officers, and the UMCP could assess the potential of agroforestry for larval control in agricultural areas of Dar es Salaam. Such an approach would be in line with the WHO guidelines for Integrated Vector Management (IVM) (WHO 2004). The study should assess aspects such as acceptance by farmers and effects on productivity and farmer's livelihoods. An alternative approach would be to merely focus on fruit trees such as avocado, citrus, mango, pawpaw, pineapple, lemon, cashew nuts, guava and banana, or neem trees.

Suggested frame: 1 PhD thesis; operational research within UMCP; potential partners for supervision: STI & University of Freiburg (IPG)

What is the potential of drainage for malaria control in UA?

Our study confirms previous findings (e.g. from Sattler et al. 2005) that a high ground water table, leading to standing surface water, is often related to presence of *Anopheles* larvae. Drainage is long known to be an effective vector control (Konradsen et al. 2004), and has also shown successes in Dar es Salaam. Establishing and maintaining an improved drainage system, either by rehabilitating existing drains where possible or by constructing new drains where necessary, could thus contribute to mitigating this potential malaria threat (Castro et al. 2004, WHO 1982). JICA in cooperation with the UMCP and the Harvard School of Public Health is currently conducting research related to drainage and its potential for reducing malaria transmission in Dar. The importance of this research is underlined by the results of this thesis. However, it should be complemented with a transdisciplinary longitudinal study about how improved drainage would (i) change agricultural productivity, crops, suitability of land for agriculture, and land value, and (ii) affect farmer's livelihoods, if agricultural land formerly not suitable for housing becomes land for building. These findings could help weigh the advantages and disadvantages of improved drainage, and thus be an essential contribution to urban infrastructure planning.

Suggested frame: 1 PhD thesis; in close co-operation with UMCP research unit at IHI and JICA, potential partners for supervision: STI, University of Freiburg (IPG), Harvard School of Public Health

Which factors contribute to larval habitat density?

Anopheles breeding sites outside agricultural areas, constituting the large majority of breeding sites in Dar es Salaam, should be investigated in similar depth as with agricultural ones. The suggested approach would be to create larval habitat density maps of *Anopheles* mosquitoes in three urban wards of Dar es Salaam. This could be achieved by combining the UMCP larval database for the pre-larviciding period as used in chapter 7 (UA and *An.* habitats) with the TCU maps as described in chapter 5 (Participatory mapping). For each TCU, habitat density could be calculated as the number of breeding sites with *Anopheles* larvae per m^2, taking the average over a whole year. The resulting map could then be integrated into a GIS database. Then, each TCU should be assigned (i) minimum/mean altitude based on the pixels of a high resolution Digital Elevation Model, (ii) minimum distance to rivers and drains, (iii) land use and settlement structure in the TCU, e.g. "high density informal settlement", and (iv) proportion of agricultural land cover classified into high/medium/low malaria threat based on the results of this thesis. This would give a clearer picture on the impact that topography, hydrology, settlement structure and land use in general have on the occurrence of all *Anopheles* breeding sites, not restricted to agricultural ones. Furthermore, the TCUs with highest (and lowest) potential and actual breeding site threat could be identified. These insights could help designing the appropriate combination of strategies that could comprise an integrated malaria control effort in malaria-endemic cities.

Suggested frame: 1 Master's thesis; operational research within UMCP; potential partners for supervision: STI & University of Freiburg (IPG)

Does urban agriculture imply intra-urban mobility?

Although many agricultural areas disappeared due to urban expansion, others newly emerged elsewhere in the city. Despite all spatial dynamics, the overall spatial extent of urban agricultural land use in Dar has thus remained in a state of equilibrium for decades. However, it is not known whether it is the same farmers that cultivate these areas, if they are mobile, i.e. moving from the former to the new sites, or if the disappearance of agricultural areas forced farmers to stop farming and establish other ways to support their livelihoods instead. A cultural geographic study could explore whether UA can contribute to sustainable livelihoods

(DFID 2000) given these dynamic conditions, and which strategies farmers apply in order to achieve this goal.

Suggested frame: 1 Master's thesis; supervision by STI & University of Freiburg (IPG)

Has the UMCP fostered resilience-building processes since 2006?

Six months after commencement of larvicide application by UMCP in 2006, "knowledge and sensitisation" gaps were identified between household members, local leaders, and UMCP workers. A follow-up study using a similar qualitative approach as described in chapter 8 (building multi-level resilience) could assess if these gaps have become smaller or have even disappeared in the meantime. Such a survey could investigate (i) the extent in which reactive and proactive capacities of all stakeholders have changed, and the reasons for that; and (ii) what measures have initiated which resilience-building processes. This survey would result in recommendations regarding the best interventions supporting resilience-building processes in the context of UMCP. These interventions could then be intensified accordingly.

Suggested frame: 1 Master's thesis conducted by a social scientist; operational research within UMCP, contributing to a monitoring and evaluation (M&E) component of UMCP; potential supervision by University of Basel, Institute of Social Anthropology, and STI

9.2 Prospects for implementation

Upscaling of participatory mapping in Dar es Salaam

The participatory mapping procedure as described in chapter 5 is currently in the process of being scaled up to an area comprising two million inhabitants, covering almost 450 km^2 of urban Dar es Salaam. This process is part of the activities of the "Malaria Transmission Consortium" funded by the Bill and Melinda Gates Foundation[26]. The availability of administrative boundary data at an unprecedented level of detail appears to have reached a level of coverage that makes it interesting to a variety of other institutions and organisations. Several requests to use the data for other purposes have already been made to the UMCP management (Khadija Kannady, personal communication). However, before the data can be

[26] http://neuron2.cc.nd.edu/mtc/index.php/Main_Page

shared, it will have to be cleaned with respect to artificially created boundaries that are only applicable in the UMCP context. The constantly growing database should therefore be managed in a way that makes it readily applicable and transparent also for other parties, and to make it available free of charge where appropriate.

Upscaling of participatory mapping beyond Dar es Salaam

The participatory mapping procedure was designed in a way that can also be implemented in other cities, and thus not restricted to the Tanzanian context and control of mosquito-borne diseases. It can be implemented with minimal cost and technical requirements. All community-based programmes that aim for comprehensive coverage of an intervention may be potential users. One of the big advantages of this procedure is that it allows field workers to use maps tailored to their personal preference, not necessarily "correct" maps that cannot be read by everyone. In the case where mapping of yet unavailable boundary data is required, like in Dar es Salaam, participatory involvement of all the parties that may be interested in the data to be collected should be ensured in an early stage. Stakeholder workshops could be held in the planning phase of the mapping activities, and involve, for example, city council representatives, city planners, mapping departments, land registry offices. In this way, the mapping can be adapted in a way that allows optimal applicability for all potentially interested parties.

Operational larviciding in agricultural areas

The direct implication of the results in chapter 7 would be to make sure that all gardens with increased potential for larval presence are known and treated by the responsible CORPs. The next step, without overemphasising the importance of agriculture, would be to integrate the additional knowledge about factors frequently associated with the presence of *Anopheles* larvae in Dar es Salaam's agricultural areas in UMCP staff training procedures. This could enhance the CORPs awareness for areas that may contain *Anopheles* breeding sites, and thus increase the proportion of breeding sites found and treated by CORPs. Features indicating nearby presence of breeding sites may be sugar cane, leafy vegetables and sunken beds, particularly in lowland locations and mid-sized gardens. CORPs should continue to keep an eye on large areas, rice fields or raised beds.

Involving farmers in malaria control

Rather than being a risk factor, farmers should be regarded as an asset in malaria control. They are usually working in their gardens on a daily basis. Based on the findings in chapter 7, and UMCP knowledge of areas with high larval abundance, selected farmers might be offered to become "associate members" of the UMCP. Those interested may then be given the necessary training, and provided the amount of larvicide needed to regularly treat irrigation wells or surface water in their gardens. In these areas, the CORPs could then take on monitoring and evaluation (M&E) functions, by regularly verifying correct and effective application.

In general, farmers with gardens that frequently contain malaria vector larvae should be made aware by the UMCP of the breeding sites in their gardens, and be motivated to actively seek support by the UMCP, e.g. by asking CORPs to treat these sites. Farmers should be made aware of the options they have to mitigate the larvae problem themselves, for example by providing shade around wells by planting trees, or by relocating wells closer to existing trees. Environmental modification options such as levelling the surface or drainage should also not be neglected, although farmers may hesitate to adopt such measures due to – real or feared – negative effects on their yield.

"Farmer field schools" might be an entry point for participatory involvement of farmers in malaria control. Farmer field schools use experiential learning methods to build farmers' expertise, including agricultural methods to suppress mosquito breeding, source reduction and integrated pest management. This intervention has been successfully implemented in a wide range of settings already, and may have the potential for adaptation in the urban context of Dar es Salaam (van den Berg & Knols 2006, van den Berg et al. 2007).

Involving farmers and community members in general is also of crucial importance with respect to sustainability of the UMCP. Being an externally funded programme, there is always a danger that programme activities will be terminated without substitution. Strengthening the capacities of farmers and community members, for example by enabling them to prevent and eliminate *Anopheles* breeding sites themselves, could thus essentially contribute to the sustainability of vector control.

CORPs as key players in community sensitisation

Social scientific research in the frame of this thesis has shown that the CORPs could not only play a key role in larval surveillance and control, but also in sensitising and educating community members on how to eliminate breeding sites themselves. They can act as key players to initiate social learning on various levels within the UMCP context. Their individual and daily interaction with community members still is a largely untapped potential in this respect. Training modules for CORPs could therefore be developed that aim at enhancing their communication skills related to (i) adequately approaching community members, (ii) competently informing them about the work of UMCP, (iii) motivating them to become active in breeding site elimination themselves and (iv) conveying the necessary information about what exactly community member could do, why, and how. Appropriate and user-friendly information material for all target audiences should be developed by Information, Education and Communication (IEC) experts, and used by the CORPs in their interaction with community members. Such materials could include comics, images or leaflets with clear key messages. Existing UMCP materials may be reviewed and improved if necessary.

However, not all people possess the same communication skills. This aspect should thus become a criterion when recruiting new CORPs, although this might imply paying higher salaries. In particular, older CORPs may be more respected by community members than younger ones in the local context, which may positively influence the commitment with which they do their work (U. Fillinger, personal communication). The UMCP management might thus recommend to recruit senior CORPs, or to let younger CORPs work in “tandems” with older ones.

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APPENDIX 1: RÄUMLICHE MUSTER UND AUSWIRKUNGEN DER URBANISIERUNG: DAS BEISPIEL DAR ES SALAAM, TANSANIA

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Figure 0.1: Ansichten einer afrikanischen Stadt. Dar es Salaam 1999 (Foto: Dongus)

Einleitung

Die Weltbevölkerung hat sich seit Beginn des 20. Jahrhunderts mehr als vervierfacht. Seit 2008 leben zudem mehr Menschen in Städten als auf dem Land. Denn: Der weltweite Verstädterungstrend, angetrieben durch natürlichen Bevölkerungszuwachs und Zuwanderung aus dem Umland, scheint unaufhaltsam. Derzeit ist vor allem das sub-saharische Afrika betroffen, wo der Prozess sehr dynamisch abläuft (UN 2007b, 2008b). Folge dieser Entwicklung ist zunächst die räumliche Ausdehnung der Siedlungsstrukturen, die auch auf Satellitendaten und Luftbildern deutlich sichtbar ist, und daraus rekonstruiert werden kann. In afrikanischen Städten fallen hier besonders die ausgedehnten dicht besiedelten Armenviertel oder so genannten „informellen Siedlungen" ins Auge, die im englischsprachigen Raum auch als *compounds, shantytowns, informal settlements*, *low-income communities, squatter housing* oder *slums* bezeichnet werden Im sub-saharischen Afrika leben 72% der urbanen Bevölkerung unter solchen Bedingungen (UNFPA 2007: 16). Informelle Siedlungen heben sich durch ihr ungeplantes und wild wucherndes Wachstum deutlich von geplanten Stadtvierteln auf den Satellitenbildern ab, und nehmen inzwischen in vielen afrikanischen Städten den größten räumlichen Anteil des Stadtgebietes in Anspruch. Dieses schnelle Wachstum geht einher mit wachsender Armut und Herausforderungen wie Arbeitslosigkeit, Sicherung der Ernährung, Krankheiten und Luftverschmutzung, aber auch mangelnder Infrastruktur hinsichtlich

Gesundheitsdiensten, Wasserversorgung, Sanitärsystemen und Müllentsorgung (Hardoy et al. 2001, Harpham & Tanner 1995, UNFPA 2007).

Die mit 2,9 Mio. Einwohnern größte Stadt Tansanias, Dar es Salaam, ist dafür ein Beispiel von vielen. Es zeigt, welche Auswirkungen der Urbanisierungsprozess hat, wie sich die räumlichen Veränderungen auf die Überlebensstrategien auf Haushaltsebene auswirken, und welche Antworten die Gesellschaft auf diesen Prozess hat. Neben den Problemen, die die wachsende Zahl und Dichte von Menschen in Städten zur Folge hat, werden Lösungsmöglichkeiten veranschaulicht, die wiederum der Urbanisierungsprozess erst ermöglicht.

Urbanisierungstrends

Knapp vier von zehn Menschen in Afrika leben in Städten. Dabei bestehen regional deutliche Unterschiede, beispielsweise zwischen dem östlichen und dem südlichen Afrika (mit 24% bzw. 59% städtischem Anteil). Dies wird sich bis zum Jahr 2050 jedoch voraussichtlich drastisch ändern und besonders im südlichen Afrika zu einer Urbanisierungsrate führen, die der heutigen in Westeuropa ähnlich sein wird.

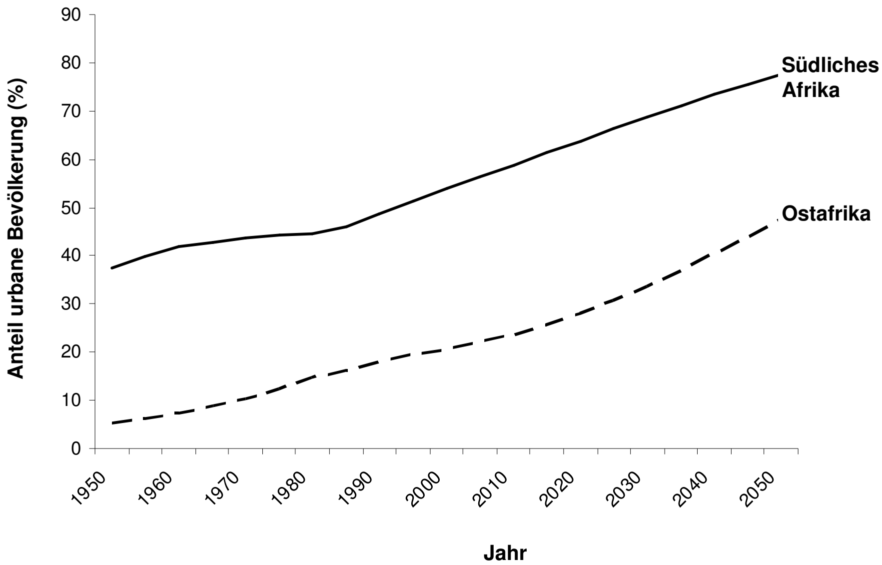

Figure 0.2: Urbanisierungstrends in Ostafrika und im Südlichen Afrika (UN 2008b)

Table 0.1: Bevölkerungsentwicklung und Anteil der städtischen Bevölkerung in den Jahren 1980, 2010 und 2050; Bevölkerungswachstum in ausgewählten ländlichen und städtischen Gebieten in den Jahren 2000 bis 2005.

	Gesamtbevölkerung (in Tausend)			Städtische Bevölkerung (%)			Städtisches Bevölkerung-Wachstum (%)	Ländliches Bevölkerungs-Wachstum (%)
	1980	2010	2050	1980	2010	2050	2000-2005	2000-2005
Afrika	479 786	1032 013	1997 935	27.9	39.9	61.8	3.38	1.58
Ostafrika	145 950	332 107	692 942	14.7	23.7	47.6	3.87	2.21
Westafrika	134 782	307 436	617 033	27.3	44.6	68.0	4.01	1.62
Nordafrika	111 364	206 295	310 239	40.3	52.0	72.0	2.40	0.95
Mittelafrika	54 715	129 583	312 671	29.0	42.9	67.4	4.22	1.92
Südl. Afrika	32 974	56 592	65 049	44.7	58.8	77.6	1.99	0.01
Angola	7 834	18 493	44 566	24.3	58.5	80.5	4.82	0.84
Botswana	996	1 953	2 703	16.5	61.1	81.1	2.70	-0.65
Kenia	16 282	40 645	84 757	15.7	22.2	48.1	3.60	2.35
D.R. Kongo	28 071	69 010	186 837	28.7	35.2	63.2	4.41	2.29
Lesotho	1 296	2 044	2 356	11.5	26.9	58.1	4.05	0.14
Malawi	6 215	15 037	31 944	9.1	19.8	48.5	5.24	2.07
Namibia	993	2 157	3 041	25.1	38.0	65.3	3.04	0.63
Sambia	5 946	12 625	22 868	39.8	35.7	58.4	1.99	1.81
Simbabwe	7 285	13 760	19 112	22.4	38.3	64.3	1.93	0.07
Südafrika	29 074	49 278	55 590	48.4	61.7	79.6	1.91	-0.05
Tansania	18 681	43 542	85 077	14.6	26.4	54.0	4.19	2.07

Mittelafrika umfasst Angola, Kamerun, Zentralafrikanische Republik, Tschad, Republik Kongo, Demokratische Republik Kongo, Äquatorialguinea, Gabun, São Tomé und Príncipe (UN 2008b).

Folgen der Urbanisierung

Informelle Siedlungen

Eine Folge der Urbanisierung in Afrika ist die Entstehung und Ausbreitung von Armenvierteln, die vielerorts das Stadtbild dominieren. Von mehr oder weniger schnellem Wachstum der Armenviertel sind in Afrika fast sämtliche Staaten betroffen, mit Ausnahme von Südafrika, Libyen und Ägypten (UN-Habitat 2006). Im sub-saharischen Afrika sind vor allem Malawi, Angola, die Demokratische Republik Kongo, Lesotho und Tansania von städtischen Wachstumsraten von über 4% betroffen.

Wirtschaftsentwicklung

Ein besonderes Merkmal der Verstädterung in Afrika ist das fehlende Wirtschaftswachstum, welches sonst weltweit mit dem Verstädterungstrend einhergeht. Erklärungen hierfür sind zum einen die starke Entwicklung des informellen Sektors, dessen Wirtschaftskraft kaum je in eine offizielle Statistik eingeht, zum anderen aber zum Beispiel auch der starke Migrationdruck aus Krisengebieten und durch extreme Armut geprägte ländliche Gebiete (UNU 1997).

Armut

Eine weitere Folge der schnellen Verstädterung ist ein drastischer Anstieg der städtischen Armut, die im sub-saharischen Afrika bereits mit einem Anteil von 50% der städtischen Bevölkerung zu Buche schlägt. Dieses Phänomen wird auch als „Verstädterung der Armut" bezeichnet und führt zu allen negativen Begleiterscheinungen, die die Armut mit sich bringt: fast 30% der Stadtbewohner im südlichen Afrika haben keinen Zugang zu sicherem Trinkwasser, 20% verfügen über keine sanitären Anlagen, und die Bewohner der Armenviertel sind deutlich stärker von Unter- und Mangelernährung betroffen als die Bessergestellten (UN-Habitat 2006).

Gesundheit

Vor diesem Hintergrund scheint es wenig verwunderlich, dass der Urbanisierungsprozess auch Gesundheitsrisiken mit sich bringt. Die Bedeutung von *urban health* wird seit den 1990er Jahren in der internationalen Debatte thematisiert (Harpham & Tanner 1995). Infektionskrankheiten wie Durchfall oder Wurmerkrankungen im Zusammenhang mit der Verschmutzung von Boden, Nahrung und vor allem Wasser sind weit verbreitet, obwohl sie eigentlich vermeidbar wären (Hardoy et al. 2001: 37). Die ohnehin extrem hohen Prävalenzen von HIV/AIDS in Afrika sind im Allgemeinen in städtischen Regionen noch höher als in ländlichen Gebieten. Malariaerkrankungen sind zwar vor allem im ländlichen Raum, aber auch in Städten sehr häufig. Die WHO schätzt, dass weltweit mehr als eine Million Menschen jährlich an Malaria sterben, größtenteils Kinder unter fünf Jahren und schwangere Frauen im sub-saharischen Afrika (WHO 2008). Auch chronische Krankheiten wie Diabetes sind auf dem Vormarsch.

Infrastruktur

Neben diesen Problemen bieten städtische Räume allerdings durch die dort vorhandene Infrastruktur auch Vorteile: Arbeitsplätze, bessere Zugangsmöglichkeiten zu Bildungs- und Gesundheitseinrichtungen, ein vergleichsweise breites Angebot an Dienstleistungen, Handel und Märkte, Kultur und Unterhaltung, öffentliche Transportmittel, Elektrizität, Anbindung an das Verkehrsnetz und sanitäre Infrastruktur (UNFPA 2007).

Disparitäten städtischer Armut

Gruppenspezifische Armut

Einzelne Bevölkerungsgruppen in Städten sind durch Armut stärker betroffen als andere. Hierzu gehören generell Kinder, Frauen und frauengeführte Haushalte, ältere und behinderte Menschen und Migranten. Frauen haben in zahlreichen Ländern weniger Möglichkeiten, einen formellen Arbeitsplatz zu erhalten. Sie sind in vielen Bereichen des gesellschaftlichen Lebens benachteiligt, so etwa in der Ausbildung, im Zugang zu Krediten, im Zugang zum Gesundheitssystem, und im Zugang zu Land- und Wasserressourcen. Frauengeführte Haushalte sind in besonderer Weise betroffen: Frauen sind verantwortlich für die Nahrungsproduktion, -beschaffung und -zubereitung, darüber hinaus aber auch für die Kinder und die Bereitstellung von Feuerholz und Wasser für die Familie.

Städtische Armut

Städtische Armut betrifft darüber hinaus auch Kinder in besonderer Weise. Sie sind häufig dazu gezwungen, für ihre Nahrung oder das Familieneinkommen zu arbeiten, was zu Kosten ihrer Schulbildung geht. Kinder sind in verstärktem Maße von Unter- und Fehlernährung betroffen. So entsteht ein sich permanent selbst erhaltendes soziales Ungleichgewicht zwischen Arm und Reich. Diese Thematik ist auch im Zusammenhang mit der Verwundbarkeitsdebatte zu sehen.

Krankheiten

Infektionskrankheiten wie Malaria oder verursacht durch Mangel bzw. schlechte Qualität von Wasser treffen vor allem Kinder und schwangere Frauen (Hardoy et al. 2001: 39, WHO 2008). Dennoch betont das *World Resource Institute*, dass durch Männer geführte Haushalte (allein stehende, geschiedene oder verwitwete Männer) bezüglich der Ernährung der Kinder noch schlechter dastehen, und dass Frauen größeren Wert auf die Schuldbildung ihrer Kinder legen als Männer (WRI 1997). Hinzu kommt die Tatsache, dass arme Haushalte in der Regel relativ gesehen mehr für Nahrung ausgeben müssen als reiche, so zum Beispiel 75% ihres Einkommens in Kampala im Jahre 1998. Dies betrifft aber auch den Zugang zu und die Kosten für andere Lebensgrundlagen, wie etwa Trinkwasser, Gesundheitsdienste und Land.

Dimensionen städtischer Ernährungssicherung

Eigenproduktion von Nahrung

Eine Reaktion armer städtischer Familien auf den Mangel an Nahrung und finanziellen Ressourcen ist die Eigenproduktion von Nahrung im städtischen Umfeld. Dies ist im Grunde nichts anderes als die europäische Antwort auf dieselbe Problematik im 18. und 19. Jahrhundert, nämlich die Schaffung von Kleingärten und „Schrebergärten“, oder die Förderung von so genannten *Relief Gardens* während der großen Wirtschaftskrise in den 1930er Jahren in den USA. Als sich die wirtschaftliche Situation in den 1970ern in vielen afrikanischen Ländern und damit auch der Lebensstandard verschlechterte, wurde die Landwirtschaft die wichtigste Quelle der Ernährungssicherung und des Einkommens im städtischen Raum.

Städtische Landwirtschaft

Bereits 1987 forderte die Weltkommission für Umwelt und Entwicklung (WCED) im berühmten Brundtland-Bericht die Förderung der städtischen Landwirtschaft: „Städtische Landwirtschaft, die öffentliche Zustimmung hat und öffentlich gefördert wird, könnte wichtig sein für die Stadtentwicklung, und die Nahrungsmittelversorgung der Armen in der Stadt verbessern“. Abgesehen von der Nahrungsversorgung gerät diese Art der Landwirtschaft nun auch im Zusammenhang mit dem Klimawandel und der Energieeinsparung in die Diskussion. So empfiehlt neuerdings die Weltorganisation für Meteorologie (WMO) den Ländern, verstärkt in städtische Landwirtschaft zu investieren. Besonders aktuell ist diese Forderung im Zusammenhang mit der gegenwärtig prognostizierten deutlichen Zunahme der weltweit Hungernden, verursacht durch die derzeit schnell steigenden Lebensmittelpreise. Die ärmsten Länder sind hiervon am stärksten betroffen.

Städtische Nahrungsproduktion

In Accra (Ghana) betreiben 50% der Haushalte Nahrungsproduktion für den Eigenbedarf, in Libreville (Gabun) sind es sogar 80% der Familien, in Lusaka (Sambia) 45%, in Harare (Simbabwe) 80% der Haushalte im Sommer und 60% im Winter, in Dar es Salaam (Tansania) sind 37% der Familien in die Nahrungsproduktion involviert. 60% des Gemüsebedarfs der Stadt Dakar (Senegal) werden durch die städtische Produktion gedeckt, in Accra gar 80%, in Kampala (Uganda) stammen 70% der Hühnerprodukte aus der städtischen Produktion und in Dar es Salaam fast 30% des gesamten Nahrungsbedarfs aus dem städtischen Umfeld (Millstone & Lang 2008).

Die städtische Nahrungsproduktion ist eng mit städtischen Umweltfaktoren verknüpft. Die Erhaltung offener Grünflächen sowie die Diversifizierung städtischer Habitate für Mensch, Tier und Vegetation und von Ressourcenischen sind Beiträge zur nachhaltigen Stadtentwicklung. Sie ermöglichen die Erhöhung der Biodiversität, die Reduktion von Lärm und Luftverschmutzung und Recycling von organischem Müll und Abwasser. In diesem Sinne bietet die städtische Landwirtschaft die Möglichkeit, in die Vision einer zukünftigen nachhaltigen Stadtentwicklung einbezogen zu werden. Egal, ob der städtische Anbau auf individueller Basis erfolgt oder durch Gruppen städtischer Kleinbauern organisiert ist, er befriedigt nachhaltig und umweltschonend die Grundbedürfnisse der städtischen Bevölkerung (Drescher 1998, FAO-COAG 1999, IFPRI 1998).

Städtische Landwirtschaft in Dar Es Salaam

Siedlungsräumliche Trends

Die Hafenstadt Dar es Salaam am Indischen Ozean ist eine der am stärksten wachsenden afrikanischen Millionenstädte. Ihr Wachstum ist gekennzeichnet durch gleichzeitig stattfindende geplante und vor allem ungeplante räumliche Expansion und Siedlungsverdichtung. Dies hat einschneidende Folgen für die städtische Ernährungssituation.

Agrare Stadttopographie

Städtische Landwirtschaft ist in Dar es Salaam weit verbreitet. Im Jahr 1999 wurden 4% der Stadtfläche allein für den Anbau auf Freiflächen genutzt, die sich typischerweise entlang von

Flüssen, Straßen, Bahnlinien, und Hauptsstromleitungen finden, aber auch in Schulen und auf noch unbebauten Industrieflächen. Für die Jahre 1992 und 1999 wurden solche Anbauflächen stadtweit kartiert (Figure 0.3). In dieser Kartierung nicht berücksichtigt wurden die vergleichsweise kleinen, aber zahlreichen Hausgärten, die zu Abertausenden über das gesamte Stadtgebiet verteilt vorzufinden sind, und Reisfelder, die in der Regenzeit in den Überschwemmungsbereichen der Flüsse, vor allem im Msimbazi-Tal (Figure 0.5), bewirtschaftet werden (Dongus 2001). Die größten auf der Karte zu findenden Anbauflächen sind das Militärareal bei Kawe im Norden der Stadt, und das zum Flughafen gehörende Gebiet im Südwesten, welches mittlerweile jedoch auf Anweisung der Flughafenbetreiber nicht mehr bewirtschaftet werden darf.

Mikroebene

Ein Blick auf die Mikroebene in Dar es Salaam verdeutlicht, wie sich die räumlichen Veränderungen durch den Siedlungsdruck auf die Verfügbarkeit und Qualität von Anbauflächen auswirken und wo dauerhafte Ressourcennischen bestehen, die zukünftig nachhaltig genutzt werden könnten. Auf der anderen Seite macht dieser Blick ins Detail auch deutlich, wo Gefahren für die Gesundheit und die Notwendigkeit für ein besseres Umweltmanagement bestehen.

Fallbeispiel A

Beispielhaft ist die Entwicklung im Stadtviertel Keko Mwanga, wo zunächst Industrieanlagen entstanden und informelle Siedlungen in der Folge die dazwischen liegenden Gebieten nahezu vollständig „auffüllten“. Die Wohnhäuser wurden dabei teilweise bis direkt an den Fluss gebaut, der diagonal von NW nach SE im Bildausschnitt verläuft. Die relativ tief gelegene, häufig überflutete Fläche im Flusstal im unteren rechten unteren Bildausschnitt (schwarz umrandet) wurde 1992 komplett landwirtschaftlich genutzt (Dongus 2001). Im Jahr 2007 war ein Großteil dieser Fläche bereits mit Industrie und informeller Besiedlung versiegelt. Auf zwei kleineren Teilflächen (schwarz umrandet) fand jedoch nach wie vor landwirtschaftlicher Anbau statt.

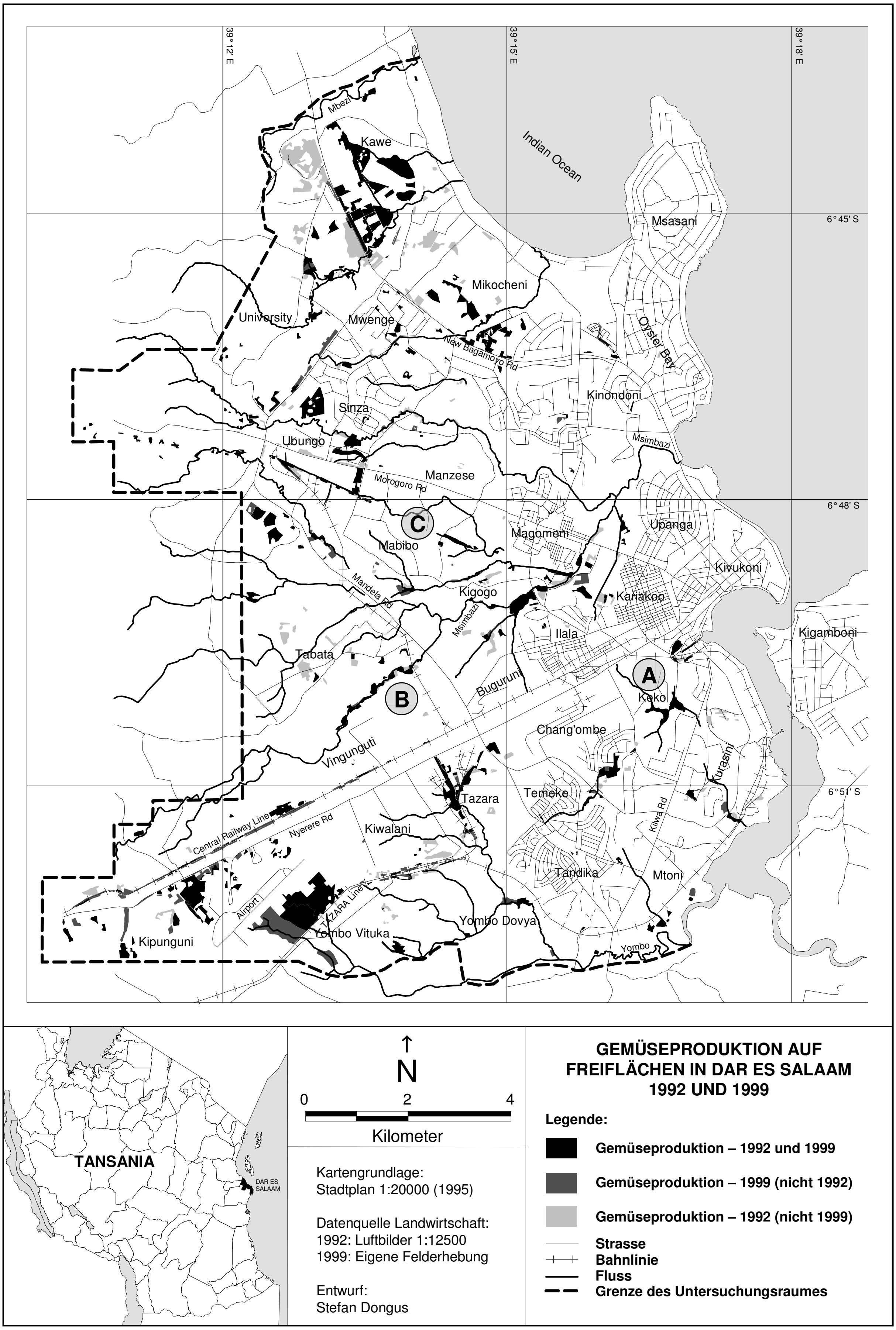

Figure 0.3: Gemüseproduktion auf Freiflächen in Dar es Salaam 1992 und 1999

A, B, C: Standorte der drei Fallbeispiele. Quelle: (Dongus 2001).

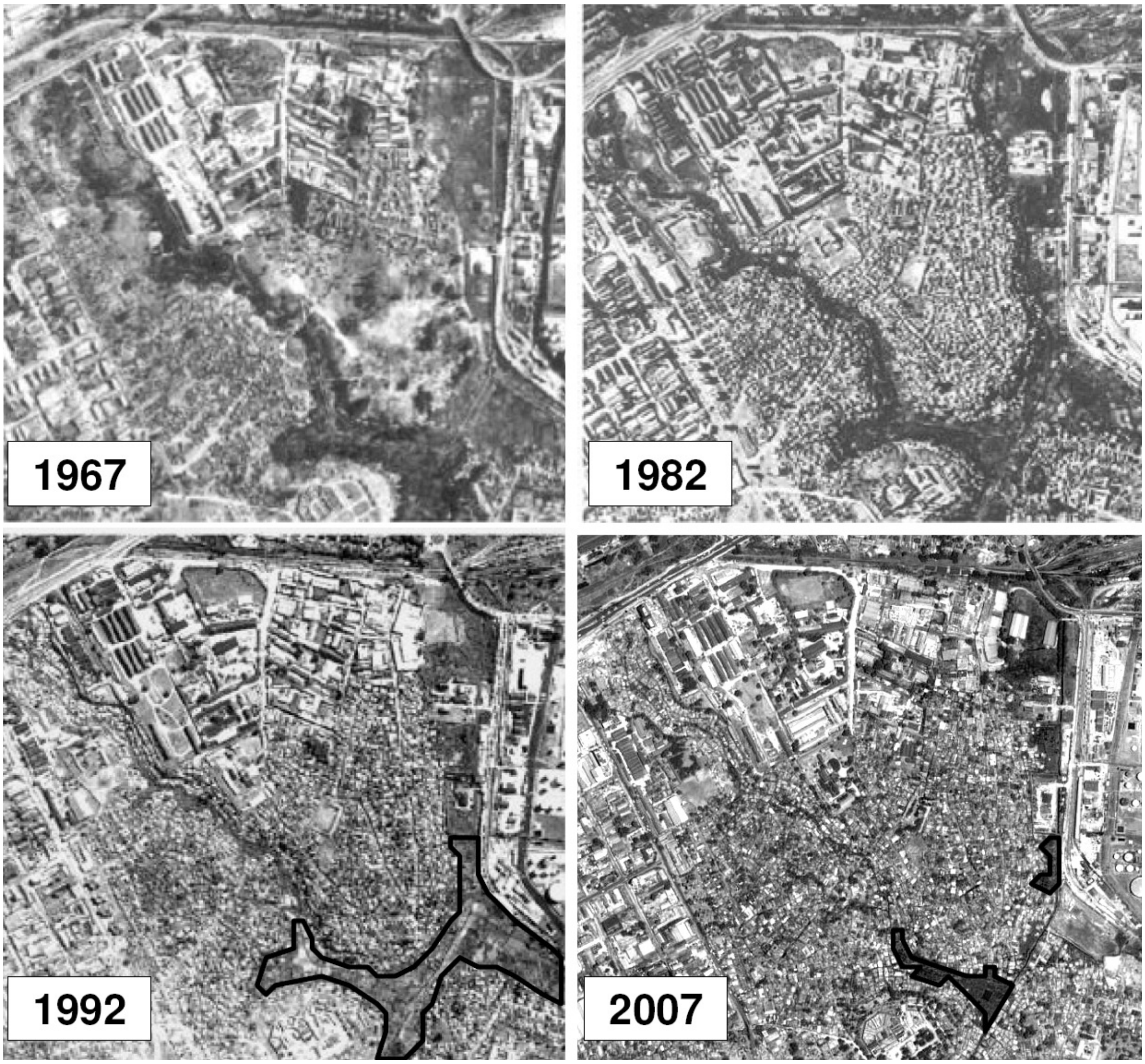

Figure 0.4: Fallbeispiel A - Keko Mwanga: Geplante Industriegebiete und informelle Siedlungen

Schwarz umrandet in 1992 und 2007: Landwirtschaftlich genutzte Freiflächen. Kartierung: Dongus; Quelle Luftbilder 1967-1992: Sliuzas (2004), Department of Surveys and Mapping; Luftbild 2007: Google Earth™

Fallbeispiel B

Während andere landwirtschaftlich genutzte Freiflächen verloren gingen, konnten die großen Gemüsegärten entlang des Msimbazi-Flusses in Vingunguti dem informellen Siedlungsdruck standhalten, der dort trotz der riskanten und außerdem illegalen Lage im Überschwemmungsbereich des Flusses mittlerweile zu dichter Bebauung geführt hat.

Figure 0.5: Fallbeispiel B – Vingunguti: Städtische Landwirtschaft und Siedlungsverdichtung im Msimbazi-Tal. Foto: Dongus 1999.

Krankheitsrisiken

Mit Landwirtschaft im urbanen Raum können jedoch auch Gesundheitsrisiken verbunden sein. So stellen durch Industrie und Haushalte verschmutztes Wasser, Abgase oder verseuchte Böden ein potentielles Risiko für Konsumenten dar, da es die Pflanzenprodukte mit Schwermetallen und Krankheitserregern verunreinigen kann. Weitere Problemfelder sind nicht sachgemäße Anwendung von Aero-Chemikalien (Birley & Lock 1999) oder der Anbau auf ehemaligen Mülldeponien.

Malaria

Malariaübertragende Mücken in Afrika bevorzugen als Brutstätte typischerweise relativ flache, saubere und offene Wasserstellen. Auch wenn es ein Irrglaube ist, dass solche Mückenlarven in Maispflanzen brüten (Birley & Lock 1999: 61), so sind sie doch häufig in diversen Wasserquellen zur Bewässerung städtischer Anbauflächen vorzufinden, beispielsweise Brunnen. Ein weiterer Zusammenhang besteht in relativ tief gelegenen Lagen, in denen stehendes Wasser über längere Zeiträume hinweg auch in Trockenperioden nicht versickert bzw. austrocknet oder der Grundwasserspiegel sehr nah an der Oberfläche liegt (Lines et al. 1994). In solchen Lagen findet auch in Dar es Salaam häufig landwirtschaftlicher Anbau statt (Figure 0.6/2 und Figure 0.6/3). Auf der anderen Seite bietet das städtische Umfeld die Möglichkeit, die Gesundheitsrisiken im Zusammenhang mit Landwirtschaft zu lindern. Potentielle Mückenbrutstätten etwa können systematisch bekämpft werden, indem man sie beseitigt, entwässert oder mithilfe biologischer Mittel unschädlich macht (Figure 0.6/4). Auch geographische Hilfsmittel wie partizipative Kartierungen der Risikogebiete haben sich als Grundlage für kommunale Malariabekämpfungsprojekte bewährt (Fillinger et al. 2008).

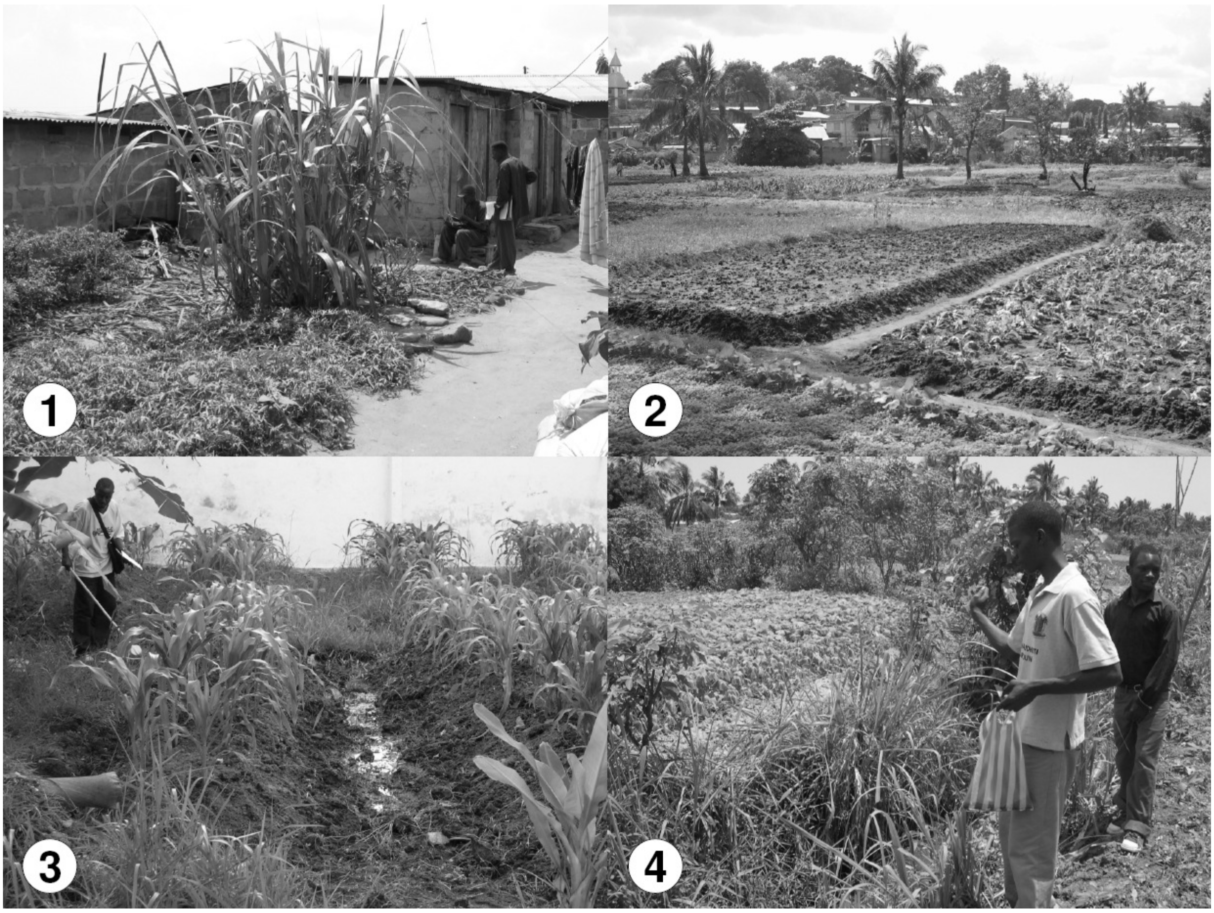

Figure 0.6: Städtische Landwirtschaft und Malariabekämpfung in Dar es Salaam

1 – Hausgarten in informeller Siedlung, 2 – Anbau auf Freifläche im Tal des Msimbazi-Flusses, 3 – stehendes Wasser zwischen Anbauhügeln als potentielle Brutstätte für Malariamücken, 4 – Bekämpfung der Mückenlarven mit biologischem Larvizid im Rahmen des örtlichen *Urban Malaria Control Programme*. Fotos: Dongus 2005/2006.

Zukunftspotential Ressourcennischen?

Fallbeispiel C

Städtische Landwirtschaft ist insbesondere dann ein nachhaltiger Ansatz, wenn die damit verbundenen Risiken durch angepasste Anbausysteme minimiert und gleichzeitig die Potentiale voll ausgeschöpft werden. Als Modell hierfür könnten organisierte Kleingartenanlagen im Sinne der europäischen „Schrebergärten“ (*allotment gardens*) dienen, die sich auch heute beispielsweise auf den Philippinen als Erfolgsmodell integrierter und nachhaltiger Ernährungssicherung erweisen (Holmer et al. 2003). Das Beispiel Dar es Salaam zeigt, dass im urbanen Raum noch längst nicht alle Ressourcennischen ausgeschöpft sind. Ein Gedankenspiel im Blick auf den Freiflächenstreifen entlang der Hauptstromleitung zwischen Mabibo und Manzese (Figure 0.7) mag dies veranschaulichen: Hier befinden sich etwa 15 ha momentan kaum genutzten Landes mitten in zwei der am dichtesten besiedelten informellen Stadtteile Dar es Salaams (Länge insgesamt 4,2 km, Breite 35-40 m). Bei einer durchschnittlichen Gartengröße von 400 m^2 pro Familie würde allein diese Fläche zur Sicherung der Ernährung von über 350 Familien ausreichen.

Figure 0.7: Fallbeispiel C – Freifläche unter Hauptstromleitung in Mabibo/Manzese: Zukunftspotential? (Foto: Dongus 1999)

APPENDIX 2: QUESTIONNAIRES AND INTERVIEW GUIDELINES

A) Questionnaire for farmers

ID:		**Plot:**		
Date:		**Municipality:**		
Mtaa:		**Ward:**		
CORP:		**TCU:**		
farming system:	❑ homegarden	❑ open space	❑ unbuilt plot	❑ paddy farm
land type:	❑ upland	❑ lowland	❑ slope area	
production type:	❑ none	❑ raised beds	❑ sunken beds	
soil type:	❑ sandy	❑ loamy	❑ clay	
animal husbandry:	❑ no	❑ poultry	❑ cattle	other:
manure used:	❑ no	❑ yes	❑ type:	
pesticide used:	❑ no	❑ yes	❑ type:	
production period:	❑ 12 months	❑ other period:		
crops grown: **1 - most dominant crop** **9 - least dominant crop**	1) 2) 3)	4) 5) 6)	7) 8) 9)	
type of irrigation:	❑ rainfed	❑ irrigated	water source:	
is there a well?	❑ no	❑ dry	❑ dug	❑ cemented
larvae in wells?	❑ no	❑ Anopheles ❑ small ❑ big	❑ Culex ❑ small ❑ big	❑ pupae
other standing water?	❑ no	❑ within agriculture	❑ not related to agriculture	
	Description:			
larvae in standing water?	❑ no	❑ Anopheles ❑ small ❑ big	❑ Culex ❑ small ❑ big	❑ pupae
remarks:				

B) Focus Group Discussion Guide

A: Instructions to Facilitators

- *To arrange the FGD: Ask the TCU leader to invite a group of resourceful persons*
- *Create conducive environment for group discussion. Break the ice*
- *Observe the sitting pattern making sure that you can see all the participants*
- *Facilitate introductions (for both facilitators and participants)*
- *During discussion try hard to remember names and keep referring people by their names*
- *Remember that this is just a guide; the quality of data will depend more on your probing skill. Listen carefully to identify room for probes*
- *Remember to fill the FGD form for participants' demographic information*
- *Record starting and finishing time*

B: Line of Inquiry

B1: Introduction

We all know that malaria is a big problem in Tanzania, especially in rural areas. Malaria also occurs in urban areas like Dar es Salaam. We would like to know whether you consider it as a problem, and if yes, what you do to protect yourself and what you think the government or other institutions do to offer protection for you.

B2: Malaria control

1. **As you all know, malaria is transmitted by mosquitoes. Where do you think these mosquitoes breed? Are there any breeding sites in your neighbourhood or in your ward?**
   Probe for grass, bushes, trees, ponds, puddles, swamps, drains, rivers, dirty water, construction pits, tyre tracks, containers, agriculture/gardening, taka taka (waste)

2. **How do you protect yourself/your family from getting malaria?**
   Probe for means such as mosquito nets, treated nets, coil, spray, repellent, other measures
   From whom and how have you learnt about that? Do you know anybody in your family/community/another part of town who manages to protect himself/her family very well? If yes, what do they do?

3. **Are you aware of any malaria control activities in your neighbourhood? Which ones?**
   Probe for cleaning/digging of drains, filling of puddles and other standing water, UMCP activities

4. **Have you ever been in contact with any UMCP staff member?**
   Probe for CORPs for habitat surveys, larviciding, household survey teams, night time mosquito catchers, staff at Ward Office

5. **What actually did he/she/they do? Did you ever talk to them? If, yes about what?**
   Probe for observed activities, and the perceived purpose

6. **How can you describe the impact of these malaria control activities (including UMCP) in your neighbourhood? Are there any changes compared to the years before?**
   Probe if there is any decrease of larvae, less mosquitoes

7. **What do you think about the "dawa" (UMCP larvicide)?**
   Probe if they know what this is, if works well or doesn't work, good/bad thing, possible fears about health risks related to dawa

8. **We know that most of the interventions on malaria protection cost money. However, what could be also improved with less or no money? What should be different from the normal and used practice of malaria control? Who could behave different? On which level (Household, TCU, Neighbourhood, Ward, Municipality, City, National)? What might improve the situation?**

9. **What do you think about the commitment in malaria control activities at different levels?**
   Probe: Is it working well? Why? What can be done to improve commitment at different levels? (Household, TCU, Neighbourhood, Ward, Municipality, City, National)
   Probe for the role of incentives such as social recognition, motivation, closer supervision and capacity building

10. **Is there anything else you would like to say about UMCP activities or any other malaria control activities in general?**
    Probe for any other concerns, thoughts, remarks etc.

C: Conclusion

Thank the participants and close the discussion. Remember to note the finishing time.

C) Guidelines for interviews – UMCP staff and local leaders

A: Instructions to Facilitators

- *Create conducive environment for discussion. Break the ice*
- *Observe the sitting pattern making sure that you face each other*
- *Facilitate introductions (for both interviewer and interviewee)*
- *During discussion try hard to remember names and keep referring people by their names*
- *Remember that this is just a guide; the quality of data will depend more on your probing skill. Listen carefully to identify room for probes*
- *Remember to fill the respondent's demographic data form*
- *Record starting and finishing time*

B: Line of Inquiry

B1: Introduction

We all know that malaria is a big problem in Tanzania, especially in rural areas. Malaria also occurs in urban areas like Dar es Salaam. We would like to know whether you consider it as a problem, and if yes, what you do to protect yourself and what you think the government or other institutions do to offer protection for you.

B2: Malaria Control

1. **As you all know, malaria is transmitted by mosquitoes. Where do you think these mosquitoes breed? Are there any breeding sites in your neighbourhood or in your ward?**
   Probe for grass, bushes, trees, ponds, puddles, swamps, drains, rivers, dirty water, construction pits, tyre tracks, containers, agriculture/gardening, taka taka (waste)

2. **How do you protect yourself/your family from getting malaria?**
   Probe for means such as mosquito nets, treated nets, coil, spray, repellent, other measures
   From whom and how have you learnt about that? Do you know anybody in your family/community/another part of town who manages to protect himself/her family very well? If yes, what do they do?

3. **Are you aware of any malaria control activities in your neighbourhood/ward/ municipality? Which ones?**
   Probe for cleaning/digging of drains, filling of puddles and other standing water, UMCP activities

QUESTION 4 & 5: UMCP staff only

4. **Could you explain to us your tasks/responsibilities related to malaria control?**
   Probe for constraints in fulfilling those, if any

5. **You must have learnt a lot during your work in controlling malaria, and have made a lot of good and bad experiences. Are you able to share those with your colleagues and supervisors? Do you think your voice is heard? Is there any impact? Is your institution able to adapt to new learnings ("to learn by doing")?**

QUESTION 6 & 7: Local Leaders only

6. **Have you ever been in contact with any UMCP staff member?**

Probe for CORPs for habitat surveys, larviciding, household survey teams, night time mosquito catchers, staff at Ward Office

7. **What actually did he/she/they do? Did you ever talk to them? If, yes about what?**
   Probe for observed activities, and the perceived purpose

8. **How can you describe the impact of these malaria control activities (including UMCP) in your neighbourhood/ward/municipality? Are there any changes compared to the years before?**
   Probe if there is any decrease of larvae, less mosquitoes

9. **What do you think about the "dawa" (UMCP larvicide)?**
   Probe if they know what this is, if works well or doesn't work, good/bad thing, possible fears about health risks related to dawa

10. **What should be different from the normal and used practice of malaria control? Who could behave different? On which level? (Household, TCU, Neighbourhood, Ward, Municipality, City, National) What might improve the situation?**

11. **What do you think about the commitment in malaria control activities at different levels?**
    Probe: Is it working well? Why? What can be done to improve commitment at different levels? (Household, TCU, Neighbourhood, Ward, Municipality, City, National)
    Probe for the role of incentives such as social recognition, motivation, closer supervision and capacity building

12. **Is there anything else you would like to say about UMCP activities or any other malaria control activities in general?**
    (Probe for any other concerns, thoughts, remarks etc)

C: Conclusion

Thank the participants and close the discussion. Remember to note the finishing time.