Urban and peri-urban agriculture and its zoonotic risks in Kampala, Uganda

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Declaration

I declare that the research described within this thesis in my own work
and that this thesis is my own composition and certify that it has never
been submitted for any other degree or professional qualification.

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To Chisako and Temma

Contents

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Abstract

In developing countries, cities are rapidly expanding, and urban and peri-urban agriculture (UPA) has an important role in feeding a growing urban population. However, UPA carries risks of zoonotic disease transmission. This study aims to understand the characteristics of UPA in Kampala, Uganda and the zoonotic risks to humans.

Following a general overview of the subject in Chapter 1, Chapter 2 describes the determination of urban, peri-urban and rural areas of the Kampala economic zone and socio-economical characteristics of the peri-urban interface compared with the urban and rural counter parts using the Village Characteristic Survey in 87 randomly selected Local Councils (LC1s). Chapter 3 describes the characteristics of UPA in Kampala and found both the contribution of agriculture to the livelihood and risks of zoonoses were high.

In Chapter 4, the most important zoonotic diseases affecting populations living in urban and peri-urban areas in Kampala were identified; brucellosis, GI infections, *Mycobacterium bovis* tuberculosis and *Taenia solium* cycticercosis based on investigations using the medical records of Mulago National Referral Hospital. Chapter 5 describes a series of case-control studies of the identified most important zoonoses using a spatial approach. The risks of identified zoonoses might be homogenously high at all levels of urbanicity. Brucellosis appeared to be the most significant disease.

Chapter 6 investigates brucellosis further, with an epidemiological investigation into the prevalence of the disease in milking cows and a quantitative analysis of the level of infection in milk for sale in and around Kampala. The prevalence was 6.2% (95%CI: 2.7-9.8) at the herd level. Chapter 7 describes the risk analysis for purchase raw milk infected with *Brucella abortus* in urban areas of Kampala. A quantitative milk distribution model was developed synthesizing the results from the cattle survey and interviews with milk sellers. The infection rates of milk at sale obtained from milk testing and cattle survey were multiplied to this model to present distribution of the risk. 11.7% of total milk consumed in urban Kampala was infected when purchased and the risk management analysis found the most effective control option for human brucellosis was construction of milk boiling centres either in Mbarara, the largest dairy production area in Uganda, or in peri-urban areas of Kampala.

List of Abbreviations

ADP	Aerial Digital Photography
AI	Artificial Insemination
AIDS	Acquired Immunodeficiency Syndrome
BAT	*Brucella* Agglutination Test
BCG	Bacille Calmette-Guérin
BPAT	Buffered Plate Agglutination Test
BSV	Banana Streak Virus
CAT	Computed Axial Tomography
CBPP	Contagious Bovine Pleuro-Pneumonia
CELISA	Competitive Enzyme-Linked Immunosorbent Assay
CEPP	Cluster Evaluation Permutation Procedure
CFT	Complement Fixation Test
CGIAR	Consultative Group on International Agriculture
CIAT	International Centre for Tropical Agriculture
CIDA	Canadian International Development Agency
CIP	International Potato Centre
CSF	Cerebrospinal Fluid
CT	Computed Tomography
DDA	Dairy Development Authority
DFID	Department for International Development
DVO	District Veterinary Officer
EHEC	Enterohaemorrhagic *Escherichia coli*
EITB	Enzyme-Linked Immunoelectrotransfer Blot Assay

ELISA	Enzyme-Linked Immunosorbent Assay
ESA	East and Sounth Africa
ETEC	Enterohaemorrhagic *Escherichia coli*
FAO	Food and Agriculture Organization of the United Nations
FIA	Fluorescence Immunoassay
FPA	Fluorescence Polarisation Assay
FPSR	False Positive Serum Reaction
GAM	Geographic Analysis Machine
GI	Gastrointestinal
GIS	Geographical Information System(s)
GLM	Generalised Linear Model
GPS	Global Positioning System
HC	Health Centre
HIV	Human Immunodeficiency Virus
HRV	High Resolution Videography
HSD	Health Sub District
ICD	International Classification of Diseases
IELISA	Indirect Enzyme-Linked Immunosorbent Assay
ILRI	International Livestock Research Institute
JICA	Japan International Cooperation Agency
LC	Local Council
LU	Livestock Unit
MRT	Milk Ring Test
MTC	*Mycobacterium tuberculosis* Complex

NCC	Neurocysticercosis
NEWRUR	Urban Pressure on Rural Areas, an European Project
NGO	Non Governmental Organization
NRSP	Natural Resources Systems Programme
NUTS2	Nomenclature of Units for Territorial Statistics 2
OD	Optical Density
OIE	World Organization for Animal Health
O-PS	O-polysaccharide
PA	Peri-urban Agriculture
PCR	Polymerase Chain Reaction
PID	Pelvic Inflammatory Disease
PRA	Participatory Rural Appraisal
PUD	Peptic Ulcer Disease
PUI	Peri-urban Interface
PWE	Patient With Epilepsy
RBT	Rose Bengal Test
RRA	Rapid Rural Appraisal
rRNA	Ribosomal Ribonucleic Acid
RTI	Reproductive Tract Infections
RVF	Rift Valley Fever
SAT	Serum Agglutination Test
SIUPA	Strategic Initiative on Urban and Peri-urban Agriculture
STEC	Shiga Toxigenic *Escherichia coli*
SVO	Sub-County Veterinary Officer

TAT	Tube Agglutination Test
TB	Tuberculosis
UA	Urban Agriculture
UBOS	Uganda Bureau of Statistics
UNCST	Uganda National Council for Science and Technology
UP	Urban and Peri-urban
UPA	Urban and Peri-urban Agriculture
UTI	Urinary Tract Infection
UTM	Universal Transverse Mercator
VCS	Village Characteristic Survey
WHO	World Health Organization

List of Figures

XIX

List of Tables

List of Boxes

1. Chapter 1   General introduction

1.1. Introduction

Until recently people living in rural areas of developing countries have been mainly regarded as poor, however, rapid urbanisation has given rise to a large class of urban poor. Many issues are arising from this rapid expansion of cities driven by economic growth and by significant flow of migration from rural to urban areas (FAO 2000). The United Nations estimates that the percentage of people living in urban areas in Africa will increase from 36.2% in 2000 to 42.8% in 2015 (United Nations 2002).

Rural people migrate to cities to seek employment opportunities. They may also move for educational opportunities, medical facilities, and for a safer existence than is offered by traditional subsistence farming which is vulnerable to natural disasters. This concentration of populations into cities is an immense challenge for food security, water supply, sanitation, and poverty alleviation. The per capita food supply is still decreasing and the proportion of undernourished people living in cities is on the rise (Drechsel *et al.* 1999).

Food crisis is now a world phenomenon. In 2007, wheat prices rose 77% and rice 16%. These were some of the sharpest rises in food prices ever. But this year in 2008, the speed of change has accelerated; between January and April, rice prices have soared 141%; the price of one variety of wheat shot up 25% in a day. The prices mainly reflect changes in demand, not problems of supply, such as harvest failure. The changes include the gentle upward pressure from people in China and India eating more grain and meat as they grow rich and the sudden, voracious appetites of western biofuels programmes, which convert cereals into fuel. This year the share of the maize crop going into ethanol in America has risen and the European Union is

implementing its own biofuels targets. To make matters worse, more febrile behaviour seems to be influencing markets: export quotas by large grain producers, rumours of panic-buying by grain importers, money from hedge funds looking for new markets. On a conservative estimate, food-price rises may reduce the spending power of the urban poor and country people who buy their own food by 20%. Just over 1 billion people live on $1 a day, the benchmark of absolute poverty; 1.5 billion live on $1 to $2 a day. Bob Zoellick, the president of the World Bank, reckons that food inflation could push at least 100m people into poverty, wiping out all the gains the poorest billion have made during almost a decade of economic growth (the Economist 2008).

To address the lack of food supply, farming in urban and peri-urban areas has been a priority as a part of the development agenda in developing countries. The practice of the farming is called urban and peri-urban agriculture (UPA). UPA plays not only a role in feeding city populations, but also in achieving other development goals; reduction of malnutrition, enhancement of job opportunities, poverty alleviation, and support of women. Such farming, however, carries with it risks to human health, in terms of general hygiene and for the transmission of zoonotic diseases – diseases transmitted between animals and humans by livestock farming (Flynn 1999). Also, farming itself may not show sustainability due to the rapid urbanisation. However many advantages UPA has, it cannot enhance development if it brings significant detrimental side effects to the people living in the urban and peri-urban areas. This review of the literature was undertaken to explore the positive and potential negative aspects of UPA, particularly with regard to livestock farming.

1.2. Definition of peri-urban Interface (PUI)

Peri-urban areas are sometimes referred to as the peri-urban interface (Adam 2001), peri-urban space (Chaleard 1999), and peri-urban rural zones (NEWRUR 2004d). According to FAO (2000), peri-urban areas are those areas surrounding cities which are in most ways integrated with the city. These areas exhibit high growth rates and receive up to 70 percent of the migrants from rural areas as well as migrants from the city itself. There are several expressions which define a peri-urban area. Chaleard (1999) explains in his research in Ivorian Coast that 'The peri-urban space is by definition a transitional area between town and country, it is an unstable, constantly changing space, as it is a former countryside area being urbanized to a greater or lesser degree'. In France, Cavailhes *et al.* (2004) defined the peri-urban belt which is a new pattern of urban development witnessed last 30 years, as a belt outside the city occupied both by households and farmers.

Recent focus on peri-urban areas as a major development issue enhanced research activities in these areas. However, because of the lack of a precise definition of the peri-urban interface (PUI), even in the scientific publications, the term 'peri-urban' remains loosely defined in terms of the degree of peri-urbanicity, depending on the author regardless of the field of study.

1.2.1. Methodologies available to determine peri-urban areas

Definition of peri-urban areas has been tackled by a limited number of studies in developed countries as well as developing countries. In France, Cavailhes & Wavresky (2003) attempted to define peri-urban territory by analysing residential and

agricultural land price using a theoretical microeconomic residential location model and an econometric model. The results showed that farmland prices fall sharply close to the city and then more gently further away. His further work which used a fractal model, Sierpinski carpet, revealed that the rent was not always monotonous in distance from the origin (central business district) and influenced by accessibility to urban and rural amenities (Cavailhes 2004).

Another large scale research project called NEWRUR studied the interaction between urban expansion and surrounding rural areas in five European countries; France, Spain, UK, Germany and Greece between 2001 and 2004 (NEWRUR 2004d). According to the bibliographical review by NEWRUR, the phenomenon "peri-urbanisation" had not been studied in certain countries; in Germany, the term "peri-urbanisation" did not exist and research deals essentially with policies capable of regulating urban expansion, and in United Kingdom, "peri-urban" itself had not been explicitly defined and the effects of urban proximity on the "restructured" rural areas were paid more attention. On the contrary, other countries, for example France and Greece had had a wide variety of definitions and interpretations concerning the peri-urbanisation phenomenon. NEWRUR determined the peri-urban areas in the participated five countries with four steps. Firstly, urban zones (termed "cities") were identified based on the level and density of population and the percentage of territory occupied by man-made installations in the administrative units. Secondary, urban regions (NUTS2: Nomenclature of Units for Territorial Statistics 2; defined as counties or groups of counties populated between 800,000 to 3,000,000, by EUROSTAT (Statistical Office of the European Communities 2008)) were identified based on the percentage of populations living in the largest cities. Thirdly, urban

regions faced with "peri-urbanisation" were selected using socio-economic indicators supplied by EUROSTAT. Used socio-economic indicators were migration data, population growth, activity rates, working persons by sector, percentage of agricultural active population and percentage of agricultural land, etc.

In Quebec, Canada, the rural areas were transforming because of the decrease in the agricultural population, the spread of the peri-urban fringes, and appropriation of areas by seasonal residents. By analysing agricultural trajectories from 1961 to 1991 in local municipalities in Quebec, Paquette & Domon (1999) attempted to understand spatial and demographic dynamics of contemporary rural communities, while future remained uncertain. The study used the agricultural and socio-demographic indicators in the Canadian census of every municipality, and all municipalities were categorised into the agricultural rural area, the periurban rural area, and the rural amenity area.

These studies in developed countries were enabled by availability of precise, unbiased and rich sources of data from national censuses or public databases. What makes analyses difficult in developing countries is the absence of data. The methodologies of determining peri-urban interface (PUI) were well explored by the Natural Resources Systems Programme (NRSP) funded by the UK Department for International Development (DFID), studied in two medium sized city regions: Kumasi in Ghana and Hubli-Dharwad in India (Adam 2001; Brook 2000). The explored methods were satellite imagery (Landsat or SPOT) (Mather 1996), colour infrared aerial digital photographic (ADP) system survey, the micro light platform- a low cost and compact aircraft, the balloons platform (D'Souza 2000; Brook 2000),

high resolution videography (HRV) (Curr 1996) and integration of rapid rural assessment (RRA)/participatory rural appraisal (PRA) and geographic information systems (GIS) called rapid rural mapping (D'Souza 2000; Brook 2000). Several studies on urban sleeping sickness also used satellite imagery (SPOT 4) to delineate urban, peri-urban and rural areas in Kinshasa, Democratic Republic of Congo (Deken 2005; Robays 2004; Simo 2006).

Above all, Adam (2001) successfully described the demarcation of PUI in Kumasi, Ghana using three approaches based on Rapid Rural Mapping called Village Characteristic Survey (VCS). The three approaches were; firstly, to identify the differences of agricultural production among urban, peri-urban and rural farming systems and the changes occurring therein; secondly, to consider market and transportation systems and their spheres of influences; and thirdly, to apply cluster analysis to find socio-economic indicators of PUI. These results showed that a village could be selected as a unit for analysis, and that PUI could be presented not as a continuous belt or line around the city but as points (peri-urban villages existing mixed in with urban and rural villages).

1.2.2. Characteristics of peri-urban areas

From a spatial point of view, peri-urbanisation shows a progressive integration of rural zones into urban systems, with scattering effects around important cities. From a functional perspective, peri-urbanisation will strengthen synergies between rural zones and cities. In this way, peri-urbanisation can lead to an increase in urban-rural links (NEWRUR 2004b). In Rhône-Alpes and Provence-Alpes-Côte d'Azur, France,

the peri-urbanisation gradient expressed not only the geographical proximity, but also other integration factors. For instance, economic links, expressed through commuter's displacements flows, are moderately correlated to geographical proximity. In Upper Bavaria, Germany, the communities in peri-urban rural zones did not have a high population density, and had a large proportion of commuters to the city. They were expressed as "growing municipalities", with regard to the fast economic development such as demographic dynamics, development of employment opportunities, attractiveness for younger families and migrants from urban areas. In Attiki, Dikiti Ellada and Thessalia, Greece, the most peri-urban rural zones were characterised by the highest percentages of developed infrastructure, highest housing development, highest provision of public services or highest provision of offices and professional private services. They have developed a strong relationship with towns. In Andalusia and Murcia, Spain, in addition to the geographical proximity to urban cores, administrative links with centres (political and administrative factors) correlated with peri-urbanisation in traditionally agricultural non-industrial regions. However, the analysis revealed less directly a peri-urbanisation gradient than in France or in Germany. In Bedfordshire-Hertfordshire and East Anglia, UK, as in Spain, the analysis revealed more the diversity of peri-urbanisation forms in rural areas than really a geographical peri-urbanisation gradient. More than half of the peri-urban wards fell into the cluster defined as higher income zones, and other peri-urban clusters were characterised by relative dominance of some activities (energy or minerals, retail trade, manufacturing activities) or by rapid housing growth (NEWRUR 2004b; c).

In Quebec, Canada, periurban rural areas were displayed clearly around small

regional centres, and the characteristics were the setting of young families, a socio-professional diversity (high proportion of the secondary and the service sector), and higher incomes. The population density and residential land value were high, however the areas included the municipalities with an agricultural predominancy at the same time (Paquette & Domon 1999).

Indicators of a peri-urban settlement (Box 1.1) and characteristics of peri-urban interface in Kumasi, Ghana (Box 1.2) were well described by Adam (2001).

Box 1.1 Indicators of a peri-urban settlement in Kumasi, Ghana

1. Cost of minibus to city centre is in the intermediate range.
2. More than twice as likely to have ongoing land disputes than either urban or rural settlements.
3. More likely to have a junior secondary school.
4. More likely to have a health clinic (as opposed to a hospital or no health facilities at all).
5. Recent improvements in health, electricity and public toilet facilities.
6. However, human waste management likely to be an important problem.
7. Environmental degradation less recognized than elsewhere in recent years.
8. More likely that farmers sell their tomatoes in Kumasi.

Box 1.2 Characteristics of peri-urban interface in Kumasi, Ghana

1. Dynamic in space and time.
2. Areas within the zone are heterogeneous.
3. Competition for land between agricultural and non-agricultural uses.
4. Competition for jobs between agricultural and non-agricultural work.
5. Changing social and economic balance between indigenous and immigrant inhabitants.
6. Increasing dependence on urban centre.
7. Increased facilities that may speed up development.
8. Increased pollution and waste disposal problems.

The peri-urban interface (PUI) in Habli-Dharwad, India, was dynamic in terms of socio-economic, institutional and environmental change, with intensive flows of commodities, labour, waste, pollution, and energy between urban and rural areas (Adam 2001). Villagers feared increased air and water pollution from a growing city and loss of common land and open space (Patil 1999). The PUI was the chosen location for the cities landfills, where waste pickers operate (Brook 2000). Women living in rapidly changing PUI were particularly under threat to their livelihood in Kumasi and Accra in Ghana, and Habli-Dharwad. This was because women were more likely to depend on their farms for livelihoods than men (Adam 2001; Armar-Klemesu 1998).

The heterogeneous feature of the peri-urban interface is described in several studies. In Kumasi, "neither a pattern of peri-urban settlements following the main roads nor one related to radial distance from Kejetia (the centre) can be distinguished readily" (Adam 2001). This feature was found by Cavailhes *et al.* (2004) in France and Paquette & Domon (1999) in Canada as well, and it hindered determination of the

exact peri-urban interface. Drechsel *et al.* (1999) found that the intensive vegetable farming system was characteristic of the peri-urban area, but he also added that "however, even if we focus only on vegetable farmers as a potential peri-urban target group, we will find that this group is not homogenous, even around the same town".

1.2.3. Types of urban formation

In terms of spatial structure of a city, there may exist polycentric and monocentric urban systems (NEWRUR 2004a). For example, the metropolitan area of Athens is termed "macrocephalic" if all its satellites are included, and thus the city has a polycentric urban system. This situation is consistent with the overall European trends. In UK, the concept of the regional city is seen to be an emergent urban type with a dispersed form. In UK the mono or polycentric system is central in the metropolitan reflection. France shows the general characteristics of the European urban frame although the weight of Paris is so much higher, and for this reason we can say that at national level this country exhibits a monocentric morphology. In Spain, the crucial role of geography has produced a very particular spatial structure with fairly evenly distributed smaller towns in certain regions, compared with other more monocentric regions (NEWRUR 2004a). A review of the history of urban formation is a useful tool to determine the PUI of the city. Habli-Dharwad in India, a polycentric city, was formed merging two cities, Habli and Dharwad due to their expansion (Brook 2000).

1.3. Characteristics of urban and peri-urban agriculture (UPA)

Urban agriculture and peri-urban agriculture are independent terms but there has been a recent tendency to combine urban and peri-urban agriculture as a single research and development area (Adam 2001), UPA, 'urban and peri-urban agriculture'. UPA- is sometimes called (intra- and peri-) urban agriculture (UA) (Mougeot 2000). UPA is perceived as agricultural practices within and around cities that compete for resources (land, water, energy, labour) that could also serve other purposes to satisfy the requirements of the urban population that exhibit common features such as adaptability and mobility as compared with rural agriculture. Important sectors of UPA include horticulture, livestock, fodder and milk production, aquaculture, and forestry (FAO 2000). On the other hand, Mougeot (2000) suggested the necessity to add a distinction between intra-urban agriculture and peri-urban agriculture to diversify and strengthen urban management strategies.

According to FAO (2000), "Urban" agriculture (UA) refers to small areas (e.g. vacant plots, gardens, verges, balconies, containers) within the city used for growing crops and raising small livestock or milk cows for owner-consumption or for sale in neighbourhood markets. "Peri-urban" agriculture (PA) refers to farm units close to town which operate intensive semi- or fully commercial farms grow vegetables or other horticulture or raise chickens or other livestock. However, the boundaries between urban, peri-urban and rural activities are ambiguous, they are fluid, presenting opportunities for potentially beneficial linkages.

1.3.1. Opportunities of UPA

1.3.1.1. Market demand

UPA presents opportunities in terms of market drivers, since food demand is high because of its proximity to the cities and towns. Intensive commercial farms in peri-urban areas make use of this high demand for food in the cities. There is variety in types of UA, with the majority of production being directed towards own consumption with occasional additional income benefits through selling homemade products to households directly, or locally using the informal marketplace, and through part-time farming practices (FAO 2000).

The low costs of packaging, storage and transportation present good opportunities. In developing countries, UPA is suitable for production of fresh and perishable foods including leafy vegetables, meat, milk and eggs, since transportation to the city is a significant challenge for rural agriculture. Freshness increases the intrinsic value of foods in terms of nutrition and hygiene. Additionally, post-harvest losses can be prevented. Conversely, the production of preservable foods such as cereals or potatoes is more suitable for rural agriculture because of land volume for cultivation.

1.3.1.2. Food security

Food security is an important role of UPA. In African cities, civil servants are prone to take part in this activity because the 'real income' has become insufficient for family survival (Ellis & Sumberg 1998). Very poor urban dwellers also often do not have sufficient capacity to buy adequate amount of foods in the market. For these people, urban agriculture can serve to reduce food insecurity, through own

consumption from agricultural activities or by purchasing from cheap, informal markets. In Kampala, Uganda, a significant association was observed between farming in the city and improved child nutritional status (Maxwell 1995). Moreover, UA plays an important role in emergency food supply. It can provide foods to the people in cities even during times of national crises and severe scarcity such as civil war, widespread drought, currency devaluations, inability to import, or household crises such as illness, sudden unemployment (FAO 2000). In Uganda, the formal economy of Kampala was severely damaged by the "war of economic independence" during the regime of Idi Amin between 1971-1979, (Maxwell 1995). In Tanzania, the impact of an extended period of economic hardship, and the government's programme of economic liberalisation and structural adjustment enhanced urban agriculture as a measure of food security (Sumberg 1999). Both cases resulted in falling 'real wages' of civil servants and middle class urban residents, which lead to their engagement in agricultural activities to provide additional income and self-consumption of food. The different approaches of governments and land institution frameworks impact differently on their agricultural systems. Cuba's response to food insecurity caused by the collapse of the eastern European bloc and intensified US economic blockades in the early 1990s also supports this idea. When the food crisis hit, many people in urban communities began to farm in empty lots. Policy makers and state agencies realised the potential of UPA and declared it a national priority. As a result, food became more available and prices decreased dramatically. The recovery is largely due to the policy of encouraging UPA at a community level (Bourque 2003). Also, UPA may critically flattens prices/ variety/ seasonality by lessening dependence on off-season imports, or making up for reduced supplies from rural agriculture during the dry season (Mougeot 2000).

1.3.1.3. Employment opportunities

UPA offers opportunities for employment in a sector with low barriers to entry. Based on a combination of national census data, household surveys, and individual research projects in specific cities, it is estimated that one-quarter to two-thirds of urban and peri-urban households are involved in agriculture (FAO 2000). In the cities and towns, UPA provides working opportunities for women, who can work only on a part-time basis because they have an important role to take care of children and other family members in a household.

1.3.1.4. Technical support

There is another opportunity for UPA to utilise public and/or private technical services, and waste treatment facilities even though they may not be sufficient. Specific agricultural techniques or services available in urban or peri-urban areas can serve to increase productivity. For example, hydroponics or substrate culture in beds as small as one metre can produce high value and nutritious vegetables in UPA (FAO 2000).

1.3.2. The risks of UPA

Despite the opportunities and potential benefits and efficiencies, UPA carries risks. Risks include increased competition for resources (land, water, energy, and labour), and environmental and health risks. UPA is always under threat of low sustainability due to the rapid expansion of the cities.

1.3.2.1. Competition for resources

Competition for resources, especially for land is intensive because land access is critical for agriculture. UPA in African cities takes a variety in forms; reflecting land access, water availability, and the potential for bringing other resources into the production process (Ellis & Sumberg 1998). Public lands and un-built private lands are used for crop and livestock production in urban and peri-urban areas. Public lands include road sides, river banks, open spaces, lands acquired for roads, power lines and other infrastructural projects. In Zimbabwe, municipal authorities designate certain public areas to lease for urban agriculture, however such cases are rare (Rakodi 1995). Public lands in the cities are often used for farming purposes illegally and with no formal or informal tenure arrangements. Therefore, city officials may sometimes destruct crops and evict these using public lands illegally for farming purposes. The degree of dependence on agricultural activity to the net household income has a wide variety in UPA, however, such cessation is often biased toward the poor rather than middle class families engaged in food production activities (Ellis & Sumberg 1998).

Private lands include own home gardens and plots purchased but not yet utilised for building or housing development. Home gardens (i.e. backyards agriculture) do not

face critical risks, but present more risks for tenant farmers as tenure arrangements between users and landowners over private lands are usually rather informal and insecure (Maxwell 1995). In many cases, UPA opportunities may be short-term, because of the rapid change of land rights, uses, and values. Under pressure from demands for residential expansion and industrial use, land sales are increasing and prices are rising in urban and peri-urban areas (Drechsel *et al.* 1999). Many urban farmers are under constant threat of losing access to their plot and being forced to stop production.

Water is an important factor for the value of the land. Demand and rental value for valley-bottom land with access to water are increasing due to agricultural pressures.

High values of land need to be covered with high productivity in a short-term. To meet demand, agricultural intensification techniques such as irrigation and fertilisers can improve food production leading to intensified and commercial vegetable farming systems in peri-urban areas (Harris 1997). However, unlike rural areas, urban household and market refuse is often accumulated to consequently cause pollution, or accumulates as landfill. That is, there is little return of biomass or nutrients to the production areas. Nutrient mining takes place at such a large scale that soils degrade and lose their production potential. To replenish soil degradation, fertilisers represent the most expensive inputs in terms of direct costs. Nutrient mining threatens UPA viability for intensive vegetable production, (Stoorvogel & Smaling 1990).

1.3.2.2. Environmental and health risks

UPA presents environmental and health hazards which are unique to city farming and intensified by urban conditions. Hazards include the use of untreated human and animal waste, reuse of urban waste, wastewater reuse, heavy metal contamination in soils and irrigation waters, insect and arthropod vector breeding pools, air pollution, pollution from chemical and industrial byproducts, hospital wastes and zoonotic diseases (Flynn 1999). In Dar es Salaam, urban livestock keeping and heavy metal contamination were two key health concerns (Sawio 1998). These hazards can be seen in peri-urban agriculture as well, as the hazards in cities such as chemical factories or slaughterhouses tend to move from urban areas to peri-urban areas with city expansion.

Urban health- geography, culture and gender

There exists an inequality in aspects of human and environmental health in urban areas that is influenced by socio-economic status, age, gender and migrant status (Flynn 1999). In the United States, the best predictor of the location of toxic waste dumps was a geographical concentration of people of low-income and colour (Harvey 1997). People who are the most vulnerable to environment hazards are those that are least able to avoid them (Hardoy & Satterthwaite. 1997). People may not be able to avoid the hazards because it is economically impossible to live in the better, higher valued lands or because they have essential roles in society that mean they have to stay close to the hazards. These inevitable roles usually derive from low socio-economical status. For example, the caste system is an inevitable cultural law in Hindu countries like India and Nepal, which determines the socio-economic status of each clan including their profession. It is difficult for them to change the

profession even though the job is hazardous to their health. Low socio-economic status often excludes people from educational opportunities, because in poor households, children also tend to have roles of a housekeeping job or even a labour work. Without proper education, people may not have a chance to know what kinds of practices are harmful to their health (from author's two years' experience of living in Nepal).

There is also an important gender dimension to understanding health hazards (Flynn 1999). The types and degree of risks differ by gender, as the time each gender spends in the work place or at home may be different. In a case study of gender, environment and epidemiology in the Greater Accra Metropolitan Area, health risks were related primarily to gender and economic status (Songsore & McGranahan 1998). The household environmental health risks to poor women were higher than the other household members because they spend more time in and around the household, while men spend more time away from the home. As the poor tend to live in environments such as squatter settlements, shanty towns, favelas, and slums, the possibility of disease transmission was high. In such an environment, water and sanitation, insect vectors and pest control methods including the use of aerosol pesticides in the crowded conditions, respiratory illnesses and poisonings related to indoor air pollution from cooking fires posed additional health concerns. A study in Kampala, Uganda endorsed the importance of women in urban agriculture. Eighty percent of the labour engaging urban agriculture were women (Maxwell 1995). Women engaging in urban agriculture tend to be exposed to diseased animals, contaminated soils or water by both chemical and biological agents the most in a household. The nature of this vulnerability makes gender-sensitive research critically

important. The gender role of women has another meaning for research in public health. Women have roles as family care-givers with additional experimental knowledge of common environmental illnesses (Kettel 1996) and as such women tend to be the key people from whom health researcher should collect information in the households.

Contamination of irrigation water, soil and crops

Crop, soil, and water pollution from industrial and chemical by-products may pose serious health risks within the urban food system. These risks to men, women, and especially children, range from occupational hazards of exposure to toxic elements by farming, handling and distributing contaminated crops, to the short and long-term effects of the consumption of food contaminated by heavy metals (Flynn 1999). Heavy metals, with specific gravity greater than 5.0g cm^{-3}, include iron (Fe), manganese (Mn), copper (Cu), zinc (Zn), cadmium (Cd), lead (Pb), mercury (Hg), chromium (Cr), nickel (Ni), molybdenum (Mo), cobalt (Co) and so on. Arsenic (As) is a metalloid, but it is often regarded as a heavy metal. The sources of heavy metal pollution in soils are plentiful and main sources are irrigation especially with sewage, solid waste disposal (sludge and compost refuse), fertilizer and pesticide application, and atmospheric disposition (Huamain *et al.* 1999).

In developed countries, people are protected from these hazards by the law and health regulations. Well-developed government monitoring systems make public and private factories, laboratories, waste treatment companies, and all bodies related to this concern abide the law. Private companies are enhanced to set their own criterion to meet the law. Besides, people can not have access to hazardous areas. However, in

developing countries, the Governments usually lack law, policy, infrastructure, and enforcement ability to keep citizens away from such hazards. Industrial and chemical pollutants are often disposed in local bodies of water or vacant land without adequate measures to protect human health (Hardoy & Satterthwaite. 1997).

There are examples of food contamination by heavy metals through urban agriculture. Upper Silesia is a geographic region of Poland which has the highest population density (900 persons/km^2) and 10% of the population of the country. Urban allotment agriculture has a 100-year history there, however, the soil is contaminated with lead, cadmium, and excessive concentrations of nitrogen compounds from 300 environmentally-hazardous factories brought to Upper Silesia due to the early industrialism through socialism. The World Health Organization (WHO) and Polish researchers revealed that 60-80% of heavy metal toxins found in human bodies in urban industrial areas were the result of consuming contaminated foods rather than through air pollution in the area. Therefore, activists are establishing a system to import organic and chemically tested foods from cleaner regions of Poland. Also, the National Polish Ecological Club is providing educational programmes to minimize the risks by teaching the difference between heavy metal absorption ratios by different plant parts. They teach that fruits and seeds are 10 times safer than leaves and roots, and discourage people from growing celery, parsley, leeks, lettuce, spinach, carrots, beets, and radishes. Better options are legumes, gourds, onions, garlic, tomatoes, and fruit trees and shrubs (Bellows 1999).

A serious health risk of heavy metal contamination in watercress, parsley, melon and lettuce was reported in Greater Cairo that has an industrial district (unpublished study by El-Fouly 1991). The study assessed the concentration of heavy metals (lead,

cadmium and zinc) in the soil. The concentrations were 10 to 40 times higher in Cairo than in rural areas. Some agricultural fields on the fringe of Cairo depend on untreated sewage water for irrigation, and further investigation is required (Gertel 2000).

Where soil is polluted with heavy metals, not only plants, but also livestock is polluted. In Jiangxi province in China, the levels of Cu, Zn, Mo, and Cd in soils and fodder near copper ores and copper-smelting plants were all rather high. The synergistic interaction of Cd and Mo resulted in a Cd-Mo poisoning syndrome with white skin and hair, diarrhoea, and marasmus in cattle. Domestic animals in these regions showed poorer nutrition and lower reproductivity, and the incidence of cancer, especially liver cancer, was very high among residents (Huamain *et al.* 1999).

In Dar es Salaam, Tanzania, urban agriculture was practiced in railway-yards polluted with chemicals, and in the harbour area, around industrial areas known to produce much toxic waste water. There were cases of toxicology reports on the river water used for urban agriculture, but soils and waters were not tested where urban agriculture was practiced (Sawio 1998).

The areas within traffic circles and road sides have a risk of crop and soil contamination from leaded gasoline. The sites which may have been used as an industrial junkyard, or a former factory; or a site where industrial byproducts are buried, and the sites where a battery recycling business is going-on are also hazardous for urban agriculture. This type of risk is unique to UPA, because land use is rapidly changing. Although research revealed high concentrations of heavy metals

in water, soil, and plants, attempting to discontinue cultivation is not a viable option for most people and some treatment methods can be quite costly. However, there are two protective methods which may be the most suitable in developing countries in terms of cost and feasibility. They are strategic garden planning or crop protection through agricultural zoning for sensitive areas and soil amelioration and management (Flynn 1999).

Health risks of livestock production

Some municipal authorities and researchers see urban livestock keeping as a public health risk (Flynn 1999). Besides, livestock keeping annoys city dwellers by noise, odours, wandering the streets, scavenging, and animal droppings at road sides.

Urban livestock keeping is usually associated with the intense, close interaction between human and animals in densely populated areas, and the lack of appropriate space for healthy practices for slaughtering animals (Flynn 1999). Such an environment enhances the chance of disease transmission between livestock keeper and animals and degrades their products, which leads to transmission to vender and consumer. Therefore, the relationship between urban agriculture and transmission of zoonotic diseases is a serious public health concern.

Environmental and health risks resulting from livestock production are categorised as live animals, slaughtering, products, drug residues, animal-feed contamination, wastes, and tanneries (Birley & Lock 1999). The categories of live animals and slaughtering include injury hazards, such as being gored by horns, kicks and falls other than transmission of zoonoses. In developing countries, the veterinary public

health situation is precarious. Lack of meat inspection and hygiene standards can not ensure public health. In addition to meat, milk is a major livestock product. Unpasteurised dairy products are major sources of transmission of brucellosis and bovine tuberculosis.

Drug residues in livestock products pose both communicable and non-communicable diseases. An example of communicable disease is the transmission of antibiotic resistant micro-organisms to humans. In some countries, large proportions of livestock receive drugs for therapy, prophylaxis or growth promotion. For example, chickens grow 10% faster when given antibiotics (Birley & Lock 1999). The constant exposure to anti-microbials, however, promotes the development of microbes resistant to those drugs. Anti-microbial resistant Salmonellosis is a threat in the world. In the USA, the outbreak of the antibiotic resistant Salmonellosis was traced to hamburgers derived from antibiotic treated cattle (Birley & Lock 1999; Conway & Pretty 1991). Moreover, anti-microbial resistance in pathogens from farm animals can be passed on to bacteria of humans through the exchange of genetic material between micro-organisms thus increasing public health costs through necessary use of more expensive drugs for treatment and longer hospital stays (Steinfeld 2004). Some of the drugs used are known to have teratogenic potential (Birley & Lock 1999). Residues of these drugs in livestock products can be a cause of non-communicable diseases. Drugs and veterinary services are more available in urban and peri-urban area than rural area especially in developing countries. Intensive farming in peri-urban area may be most related with this concern.

Contaminated livestock products with microorganisms or chemicals pose significant

human health risks. Bacterial or parasite contamination of animal feed also poses human health risks through contaminated livestock products. Contaminated animal feed by pesticides, herbicides, fumigants and heavy metals can be a cause of their residues in livestock products.

Livestock waste should be treated in a slurry tank and compost shed if available to make liquid fertilizer and mature compost. However, livestock wastes tend to be discharged into rivers or used for field crops, vegetable gardens, and fish ponds without suitable process. These practices cause parasitic or bacterial diarrhoea to humans. Naegal (Naegel 1990) illustrated the case of helminth parasites infection to humans following the use of livestock manures in aquaculture systems, such as liverfluke (*Opisthorcis viverrini*) infections in Thailand, and Garrison's fluke (*Echinostoma ilocanum*) and Schistosomiasis (*Schistosoma* spp.) infections in Philippines.

Tanneries are an important example of industrial processing of a natural resource that takes place in peri-urban areas, uses hazardous chemicals, and produces hazardous wastes (Birley & Lock 1999). The main communicable health hazard of the leather industry is anthrax. The main non-communicable health hazard is dermatitis from contact with the chemical and hides. Stillbirths and cancers are related to this industry because of the chemical.

1.3.3. Zoonoses

Zoonoses have been defined as "diseases and infections that are naturally transmitted

between vertebrate animals and man" (Palmer *et al.* 1998; Taylor *et al.* 2001; WHO 1959). Zoonoses are described here separately from other health risks because they are relevant to this thesis. With growing densities of livestock, particularly in urban and peri-urban areas, changing animal feeding practices (sourcing of input from distant areas), and shifts in dietary habits, there are growing concerns regarding the transmission of diseases and general food safety. Concerns range from the traditional zoonotic diseases (brucellosis, trichinellosis, etc.), to microbial contamination of food (*Salmonella*, *E. coli*, etc.) and to emerging diseases that can affect both livestock and humans (e.g. Nipah, avian flu) (Steinfeld 2004).

Perry *et al.* (2002) ranked zoonotic diseases and pathogens according to their impact on the poor of the world. The ranking was done by integrating the results from regional groups of West Africa, Eastern, Central and South Africa, South Asia, and South East Asia. Top 10 diseases/pathogens were anthrax, bovine tuberculosis, *Brucella abortus*, *Brucella melitensis*, buffalo pox, cysticercosis, leptospirosis, Rift Valley fever (RVF), *Toxocara vitulorum*, and trypanosomiasis by alphabetical order. Trypanosomiasis had the highest severity and the largest impact on poor people in Africa. However, considering the production system, important diseases/pathogens in peri-urban systems were *Brucella abortus*, bovine tuberculosis, anthrax, *Brucella melitensis*, *Toxocara vitulorum*, and cysticercosis in order of impact on poor people. The top three zoonotic diseases in peri-urban areas, brucellosis, bovine tuberculosis, and anthrax, are reviewed as follows.

Brucellosis primarily affects cattle, buffalo, bison, pigs, sheep, goats, dogs, elk and occasionally horses, and is characterised by abortion, retained placenta, and to a

lesser extent, orchitis and infection of the accessory sex glands in males (Aiello &
Mays 1998). In humans, brucellosis can cause chronic, undulating fever and
symptoms of generalised malaise which may persist for months or years, with
frequent recurrences. Human infection occurs via the ingestion of contaminated,
unpasteurised dairy products or following contact with material (blood, urine) from
an infected animal, and inhalation. It is an occupational hazard of those who work
with livestock including slaughterhouse workers. Eradication depends on testing and
eliminating reactors. The greatest danger is from replacement of animals (Fraser *et al.*
1991). However, this disease may hardly be prioritised for livestock movement
control compared with the diseases like foot and mouth disease in developing
countries. Other prevention strategies require the heat treating of all milk and dairy
products, and good personal hygiene by livestock and abattoir workers. Such
measures also are rarely maintained in developing countries. The loss through
abortion or calf death is a huge economic constrain for farmers (Birley & Lock
1999).

Bovine tuberculosis has important socio-economic and public health impacts.
Infection of humans with *Mycobacterium bovis* may occur by inhalation of aerosols
or through consumption of milk contaminated with the bacilli. Although
contaminated milk was the usual source of infection amongst town dwellers, farm
workers often acquired lung disease directly by inhalation (Collins & Grange 1987;
Hedvall 1941). Adult humans infected by the respiratory route through contact with
M. bovis aerosols from infected cattle develop typical pulmonary tuberculosis
(Wedlock *et al.* 2002). In African countries, human immunodeficiency virus
(HIV)/acquired immunodeficiency syndrome (AIDS) is associated with a greatly

increased risk of human tuberculosis due to *M. bovis* infection. In rural Zambia, 7.4% of cattle were positive reactors to the tuberculin test, 33% of herds contained positive animals. People suffering from tuberculosis were found to be six times more likely to live in households keeping infected cattle than in other households (Cook *et al.* 1996). In urban and peri-urban areas of developing countries, wandering animals on the streets can be a threat to people, especially for HIV/AIDS positives. In such countries, more research is required on the epidemiology of *M. bovis* in human populations. Many developed countries led to the eradication of this disease by conventional control methods based on test-and-slaughter policies. However, tuberculosis still persists in those developed countries because of the wildlife reservoir. Recent work engendered optimism of developing a new vaccine for livestock and wildlife which can be distinguished from field infection by a diagnosis assay. These technologies could offer a control strategy. In developing countries, although conventional control methods are not feasible, a new vaccine would offer a cost effective control (Wedlock *et al.* 2002).

Anthrax is most common in people who work with livestock, eat insufficiently cooked meat from infected animals, or work in animal product industries such as wool or skin processing. There are three forms of human infection: cutaneous anthrax occurs through cuts on the skin; respiratory anthrax occurs when the bacterial spores are inhaled; intestinal anthrax is the result of ingesting a contaminated animal product. As a measure against the infection, environmental and personal hygiene, vaccination, and disinfection of livestock products such as wool and fur are useful (Birley & Lock 1999).

1.4. Livestock farming in urban and peri-urban areas

1.4.1. Livestock species, size of operation, production systems

Devendra *et al*. (2005) described the livestock farming in urban and peri-urban areas as landless livestock production systems. A landless system is defined as one where less than 10 percent of the dry matter consumed is produced on the farm where the livestock are located, and where annual average stocking rates are above 10 livestock units (1 LU= 1 cattle or buffalo or 8 sheep or goats) per hectare of agricultural land (Sere 1996).

Urban livestock production is a large industry, involving many small-scale farmers and some large agri-businesses. The systems are diverse and undergo a continuous process of change. A whole range of livestock is kept in cities; the choice will depend on traditional food preferences, and capital and space availability. Buffalo, cows, goats, and sheep are raised under zero-grazing in backyards or grazed in parks, on road sides or open spaces. 'Mini' and 'micro livestock' (rabbits, guinea pigs, grasscutters, chickens and giant snails) are suited to the scarcity of space (Devendra 2005).

In Asia, urban agriculture is well established. There are modern and intensive production systems for poultry, pigs and fish. In Hong Kong, 15 % of the pigs and 68 % of the chickens consumed in the city are produced in the urban area. Also in the largest 18 cities of China, over half of the meat and poultry consumed is produced there. In Kathmendu, Nepal, 11 % of the animal products eaten was produced by urban farmers, and in Singapore 80 % of poultry products (Devendra 2005; UNDP. 1996). In Africa, urban agriculture has traditional roots, but its importance has

become prominent only recently. In Sub Saharan Africa, landless livestock production systems involving pigs and poultry, dairy cattle and, to some extent, feedlot fattening, are mainly found in urban and peri-urban areas. In East Africa, in addition to the poor, a number of elite and civil servants are involved in urban livestock production. In Latin America, intensive poultry production and dairying are on the increase (Delgado 1999; Devendra 2005).

1.4.2. Examples of urban and peri-urban livestock faming

The differences between urban and peri-urban livestock farming systems have been described by empirical investigative methods.

Dar es Salaam, Tanzania

According to Sumberg (1997; 1999), three milk production systems can be identified in and around Dar es Salaam. The first is a part-time, sideline economic activity which is characterised by small herds, feed gathered and grazed from public lands or purchased from boys who cut roadside grass and direct marketing of milk to individual consumers. These producers are predominantly middle class persons, many of whom are civil servants, and they keep animals within their residential compounds in urban areas. The second system is a specialised commercial enterprise, characterised by a small number of larger herds and paddock grazing. They transport milk to institutional customers (hotels, restaurants, hospitals and schools) or sell it through kiosks and shops in the city by small lorries and on public busses. The enterprises of this system are generally located in lower density areas at the periphery of the city. These individuals come from a variety of backgrounds: some are active or

retired military officers, civil servants, veterinarians or businessmen, and others continue commercial dairy production for several generations. The third production system is based on the surplus milk by traditional cattle keepers such as the Maasai. Maasai producers are located in distinctly rural areas more than 60 km west of the city centre along the Morogoro Road. The trade in Maasai milk is dependent on the traders who purchase milk from the producers and transport it by private vehicle to the city (Smith & Olaloku 1998; Sumberg 1997). Population density and herd size were related to the distance from the city centre; population density declined and herd size gained with increasing distance (Sumberg 1999). However, some governments have histories of setting up the large scale parastatal dairy farms at the outskirts of towns and cities to serve for urban populations (Smith & Olaloku 1998). There are several types of poultry production system within and around the cities. There were small-scale producers and large, integrated farms which supply chicks and feed to small-scale farms. Integrated farms also produced their own poultry products. The location of most of the poultry feed mills were in the rural wards at the periphery of the city. A large proportion (70%) of interviewed poultry producers was women (Sumberg 1998).

Kampala, Uganda

Maxwell (1995) described that a small number (2.5% of total urban farming) of commercial poultry producers in the city produced 70 % of all poultry products consumed in Kampala, Uganda. In urban and peri-urban areas of Kampala, all species, such as poultry, pigs, small ruminants and dairy cows were playing important roles. Poultry was the most frequently kept livestock. Pigs, small ruminants and cattle were somewhat less frequent, though not uncommon. Although

peri-urban agriculture tends to be described as intensified farming, peri-urban poultry farming was self-sufficient.

Nairobi, Kenya

Livestock are a quite common sight, especially in the open spaces in the outskirts of the city. Small scale livestock production, often combined with subsistence crop cultivation is common type. Poultry is by far the most common species, followed by goats, cattle, sheep, rabbits and pigs. Some large scale commercial farms characterised by battery hen houses and dairy cattle were seen in Karen, Langata, which is the south-western part of the city. Practices like dipping, spraying, vaccinating and using veterinary drugs are not very common. This partly explains the high mortality rate among the Nairobi livestock. Most farmers give additional feeding to their animals, such as crop residuals and/or urban waste. Livestock farming in the very-low income areas are common (Foeken 2000). Zoning regulations dating back to 1907, the colonial period, forbade livestock keeping in the city (New Agriculturalist on line 2006). By written permission called Temporary Occupation Licence, 'livestock may graze on the outskirts of the city', livestock farming was allowed in the areas (Foeken 2000). However in slum areas, since livestock keeping is illegal, the Kenyan government has warned that keeping animals in enclosed areas is a health hazard, and fines and confiscation of animals have been enforced to ensure that people comply with the law. But without employment opportunities, and with huge demand for cheap food, many slum dwellers rely on their animals for income, food security and assets for emergency (New Agriculturalist on line 2006). Public health officials are facing the difficult decision whether to allow urban livestock production because of its economic benefits and a

livelihood asset to the urban communities, or to ban it for its public health risks (Szonyi 2008).

Accra, Ghana

The main livestock kept for commercial purposes was poultry and pigs, and the farming activities were taking place on the outskirts of the city, but some occurred within Accra. Small ruminant and poultry farming was the largest farming category within the city. Keeping some animals in the home was a common feature in almost all communities in the city, especially in low-income migrant communities (Armar-Klemesu 2000).

Hibli-Dharwad, India

Cattle and buffalo occupy a very special position in Indian cities because these animals are regarded as sacred in Hindu culture. Access to grazing was limited within the city but these free-ranging animals fed vegetable waste or 'handouts' from those who are anxious to please the gods. Only larger and better-organised dairy farms grow forage crops in peri-urban and rural areas. Animals were rather more in peri-urban areas than in the city, however urban farming was common and there were 10,000 to 16,000 animals in the city. Goats and sheep were reared in the outskirts of the cities. Poultry farms were well run (Brook 2000; Khan 1997). Urban development pressure was seen in UP livestock farming. Grazing areas within the city was reducing, and the distance of livestock forage and manure carriage and the distance between dairy sites and grazing lands were increasing for cattle and buffalo farming. Intolerance to the presence of roaming animals and smells arising from the storage of manure by urban population was increasing. A significant number of

scavenging pigs were seen in the city, but Hubli-Dharwad Municipal Corporation has been rounding up pigs and sending them out of the city, to a forest area around 10km away, in response to complaints about roaming pigs and potential health risks (Nunan 2000).

Cairo, Egypt

Some 16% of Cairo households kept animals, predominantly chickens, geese, ducks and pigeons. Of the production, 95% was for home consumption, and poultry farming was almost exclusively undertaken by low-income groups in densely-populated quarters of the city. Commercial poultry production took place on rooftops of residential buildings, in small alleys and other available spaces- often also inside houses. Raising and slaughtering of sheep is a very common seasonal activity in Cairo as part of a religious practice. However, some "entrepreneurs" commercially raise sheep in the poor districts of Cairo and feed them on garbage from the dumpsites in the streets. Detailed studies were not done to answer to what extent this contaminated food feeding pose serious public health hazards. Commercial pig raising was a special type of urban livestock production undertaken by Christian minority groups. Cattle farming were mainly found in peri-urban districts (Gertel 2000).

1.4.3. **The role of livestock farming as a tool of poverty alleviation**

Livestock farming itself originally started through the animal domestication at the end of the Pleistocene age, (12,000 years ago) to address the problem of unpredictability of food supply associated with unpredictable weather (Kitalyi 2005).

Even today, livestock have a major role in reducing vulnerability by providing a multitude of benefits e.g. draught power, manure, food and transport) and by being sold to meet exceptional expenses or to mitigate the effects of crop failure (Ellis & Bahiigwa 2003; Ellis & Mdoe 2003; Livestock in Development. 1999; Welburn *et al.* 2006). Food insecurity is one of the dimensions of poverty (Kitalyi 2005). Hence livestock farming has an important role as a tool of poverty alleviation.

This review has so far emphasised that livestock farming has an important role of food security in both urban and peri–urban areas. However for intensive farms in peri-urban areas, farming has a different meaning for the farmers; as a tool of business, rather than food security.

Sumberg (1998) suggested that getting started with poultry farming is difficult for poor women. This is because even a relatively small flock requires substantial financial backing, which the poor cannot afford. Maxwell (1995) also mentioned that the very poor who did not engage agricultural activity had little chance of being involved in UPA. It is difficult for newcomer to the city to start agricultural activity, because old city dwellers have more rights to land access.

Agricultural services from specialists are prone to be hijacked by the well-informed and the better off rather than the very poor (Ellis & Sumberg 1998). From research of poultry production in and around Dar es Salaam, Sumberg (1998) concluded that the arena is not appropriate for poverty-oriented development intervention, due to constrains of limited profitability. Even poultry farming, which is the first step on the livestock ladder, is difficult to start. Urban and peri-urban livestock farming may not

have much impact on poverty alleviation compared with vegetable growing.

1.4.4. Animal health in urban and peri-urban areas

Perry *et al.* (2002) ranked livestock diseases and pathogens according to their impact on the poor in the different production systems of West Africa, Sub-Saharan Africa, South Asia and South East Asia. In the study, the following diseases were not regarded to have a big impact on poor in peri-urban production system but in the pastoral and agro-pastoral systems; Newcastle disease, *Trypanosoma evansi*, trypanosomiasis (tsetse), and contagious bovine pleuro-pneumonia (CBPP). *Brucella abortus*, ectoparasites, gastro-intestinal helminths, neonatal mortality, malnutrition, reproductive disorders, *Toxocara vitulorum* had big impacts in all of the systems including peri-urban production systems. Foot and mouth disease had impacts only in peri-urban and agro-pastoral systems. Mastitis and East Coast fever had impacts especially in peri-urban systems. As exotic livestock species whose genetic resistance against local endemic diseases is low are introduced mainly in urban and peri-urban areas, East Coast fever has big impact in those areas of Sub-Saharan Africa. Also, mastitis may be more common in peri-urban systems characterised by intensive dairy farming than the other systems. In urban and peri-urban areas, veterinary care may be more available, and vaccination for livestock infectious diseases may be applied more than in the other areas.

1.5. Policy and technical supports of urban and peri-urban livestock farming

There are pros and cons against the enhancement of UPA as governmental and international development policies in terms of food security and poverty reduction of developing countries. The recovery from a food crisis in Cuba (Bourque 2003) was a successful example of policy support of UPA. As mentioned so far, UPA plays important positive roles. However, there are many negative aspects in UPA, such as increasing competition, health risks, less sustainability.

Urban and peri-urban livestock farming also has both of those advantages and disadvantages. Moreover, the efficacy for poverty alleviation seems to be low because very poor people can not participate in it, and livestock farming contributes a large proportion of risks among those of UPA. However many risks it has, industrialised livestock production will continue to play an important role in meeting the expected increasing demands for meat and milk (the 'Livestock Revolution') in the cities and, to lesser extent, in rural areas (Delgado 1999; Devendra 2005).

In the long run, comparative advantage in production lies outside urban areas for the simple reason that land is cheaper (Ellis & Sumberg 1998). Sumberg (1999) claims that it is important not to "divert policy and limited investment funds toward agricultural activities and systems which have little long-term comparative advantage" and not to "become hostage to a utopian vision of closed, self-sufficient cities".

It is evident that two sets of policies pertain to urban and peri-urban livestock

farming. The first is "permitting urban poor the widest possible range of opportunities to piece together their livelihoods" (Ellis & Sumberg 1998). Welfare of the urban poor is best served by this, and scarce administrative capacity is saved. The second is the enhancement of rural-urban interactions (Ellis & Sumberg 1998), or in other words, urban-rural linkage (Allen & Julio. 2003). Bridging the transportation gap between potential production areas and the urban market, and investment along these lines are likely to yield rewards to both producers and consumers (Sumberg 1999).

In conclusion, it is very important for each country to assess the relevant key factors to this issue, such as the dependency of city dwellers on livestock farming, health risks, and the maturity of rural-urban linkage very well before making policy decisions.

1.6. An outline of the thesis

Chapter 2 characterises the landscape and socio-economical features of urban, peri-urban and rural areas of Kampala economic zone using a Village Characteristic Survey. Chapter 3 investigates the characteristics of crop production and livestock farming in urban, peri-urban and rural areas in Kampala to estimate the possible risk of zoonotic diseases and dependency of urban and peri-urban populations on agriculture for their food security.

Chapter 4 identifies important zoonotic diseases affecting the urban and peri-urban populations in Kampala economic zone using the medical records of Mulago National Referral Hospital, which was proved to have access from these populations. Chapter 5 investigates the spatial clustering of the identified diseases and their confounding factors, and the association of level of urbanicity to the incidence of the diseases.

Chapter 6 investigates brucellosis further, which was found to be the most significant zoonotic disease affecting populations in the areas, with an epidemiological investigation into the prevalence of the disease in milking cows and a quantitative analysis of the level of infection in milk for sale in urban and peri-urban areas in Kampala. Chapter 7 synthesizes the findings on quantified milk yielding in urban and peri-urban Kampala both infected and non-infected with *Brucella abortus* and market chain study for milk into a quantitative risk model of purchasing untreated milk infected with *B. abortus* in urban areas of Kampala from which presents control options. Chapter 8 describes highlights of the present study and finally discusses the outlook and future works.

2. Chapter 2 Determination of urban and peri-urban areas of Kampala, Uganda

2.1. Introduction

2.1.1. Aims

In developing countries, cities are rapidly expanding; by 2025 it is estimated that over 50% of the population in those countries will reside in or around cities (FAO 2002). To feed growing city populations, urban and peri-urban agriculture has become part of the development agenda (FAO 2000). However, it also carries risks of the transmission of zoonotic diseases (Flynn 1999). Therefore, research to understand the epidemiology of zoonoses in urban and peri-urban areas is urgently required. The first stage of this thesis was to determine peri-urban interface (PUI) of Kampala, the capital of Uganda, where a series of studies was carried out and to describe its socio-economic characteristics compared with urban and rural counter parts.

2.1.2. The peri-urban interface (PUI)

Peri-urban areas are sometimes referred to as the peri-urban interface (Adam 2001), peri-urban space (Chaleard 1999), and peri-urban rural zones (NEWRUR 2004d). A variety of definitions of PUI and its characteristics were introduced in Chapter 1, Section 1.2.

There are a limited number of studies on determination of the PUI but a variety of methodologies are available. The methodologies available to determine the PUI were described in Chapter 1, Section 1.2.1. In the present study, Rapid Rural Mapping was selected because sociological, health, agricultural and livestock information of communities were necessary to obtain from interviews on understanding the zoonotic risks. However, airborne image information was not collected to reduce research cost. The present study was designed based on a Village Characteristic Survey (VCS)

conducted by Adam (2001) in Kumasi, Ghana, which presented its PUI not as a continuous belt or line around the city but as points (peri-urban villages were mixed in with urban and rural villages). The criteria for the classification of the villages called LC1s (Local Councils 1) into urban, peri-urban and rural were newly developed for the present study.

2.1.3. Administration units of Uganda

The series of studies were carried out at the smallest administrative units called Local Councils 1 (LC1s) of Uganda. LC system consists of five layers: District (LC5), County (LC4), Sub-county (LC3), Parish (LC2) and Village (LC1) (United Nations 2004). LC5 covers the biggest area and LC1 the smallest.

2.1.4. History of urban formation of Kampala, Uganda

It is very important to understand the history of urban formation of the city for the determination of the PUI. Each city has its unique history that has influenced the formation, and the reasons of geographic characteristics are hidden in the history. By understanding the history of Kampala, geographical distribution of city centre, slum areas and high income residential areas, and its mono-centric feature were explained.

2.1.4.1. Beginning of the history of Kampala

According to history, Kampala is not a very old city. The oldest record relating to Kampala is in 1875 (Southall 1957). When the Christian missionary, Stanley entered Buganda Kingdom, the largest kingdom in the areas of current Uganda, he found Mutesa I (1859-1884; 30th Kabaka (King of the Buganda Kingdom), 21th generation) at his palace in Rubaga, a part of current Kampala City. Two years later

in 1877, when another missionary, Wilson visited Buganda Kingdom, Mutesa I had another palace on Nabulagala (Kasubi) hill, close to Rubaga (Fig 2.1).

There is no written record until 1862 regarding the Kingdom when Speke discovered the Kingdom and the source of the Nile River. When Speke visited Muteesa I at the royal palace of Buganda Kingdom in 19 February 1862, it was in the province of Bandawarogo (Fig 2.1), in latitude 0°21' 19" north, and longitude 32°44' 30" east (Speke 1863). This location was 20km southwest of current Kampala City centre, within Ssisa Sub-County of Wakiso District. The capital was moved from hilltop to hilltop every few years, and was invariably changed at the death of one Kabaka and the accession of another (Southall 1957). Therefore, the beginning of the history of Kampala is between 1863 and 1875.
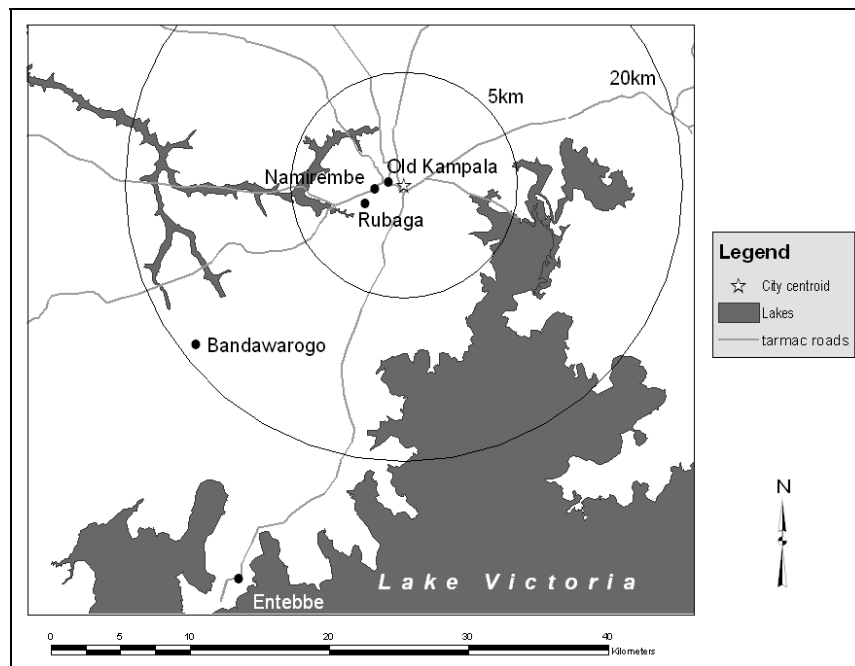
Fig. 2.1 Map showing locations of palaces of Buganda Kingdom and Kampala Hill
(Old Kampala)

2.1.4.2. The oldest description of Kampala

The oldest description of the name of Kampala appears in the diary of Lugard as Kampala Hill (now called as Old Kampala). Lugard was sent to Buganda Kingdom by the Imperial British East Africa Company in 1890. When he arrived, the palace was in Mengo hill of current Kampala. Lugard depicted the scenery of Mengo in his diary in December 1890. As he entered the kingdom, he was amazed, after all he had seen of emptiness and of primitive humanity on his march, at the degree of civilization in this remote place. He marked the roads, the tall, regular fences, the people's long garments of russet bark cloth or spotless imported cotton, and their dignity and respectful manners. He marched westwards parallel with the lake, through Buganda's alternation of low, grassy, flat-topped hills and its forested lowlands, descending at intervals into swamps of black mud matted with beautiful plumed papyrus and water-lilies. Round each hut were the dark cloisters of the banana groves which supplied the staple food of the people (Perham 1956). Lugard seized a well-sited hill top called Kampala in 8 December, 1890 (Rowe 1969). Mengo Hill is not shown in Fig 2.1 but located near Namirembe.

2.1.4.3. British colonisation

The capital of Uganda was built on four hills, Mengo, Rubaga, Namirembe and Kampala, the first three being occupied by the king, the Catholic and Protestant missions respectively, while the last was selected by the officers of the (Imperial British East Africa) Company as the site for their fort (Colvile 1895; Southall 1957). Whereas in 1890 the little fort on Kampala hill and the houses of the missionaries on Namirembe and Rubaga were insignificant by concentration of the King's capital on Mengo, by 1906 the position was reversed by the rapid development of the British

administrative post and the Asian bazaar which sprung up beside it. Despite this rapid growth of Kampala, Entebbe was selected as the political capital of the Uganda Protectorate by Sir Gerald Portal in 1893 (Southall 1957), and it remained until 1968 when the capital was relocated to Kampala at the independence of Uganda.

2.1.4.4. Formation of slum areas

In 1920s to 1930s, "As more of them came into Uganda as administrators or merchants, Europeans were living increasingly segregated lives. A rapidly growing urban area, Kampala became a well laid-out town with almost no African residents. It had spacious homes, gardens, and a social life that was entirely Europeans and Asian". When the Labour Party came to power in England in 1945, the policies for local government reform and economic independence started in colonial world. As European and Asian commercial activities expanded, Africans began to enter trade in very large numbers, although in 1952 still only 2.5% of the traders in Kampala were African. African trading outlets developed in Katwe, near Mengo, the seat of the Buganda government and the palace, and Wandegeya, adjacent to Makerere College (Fig 2.2). This urban area in crowded slum conditions was not under municipal control of Kampala. Petty traders short of funds, competing with Asians, lived adjacent to the rapidly growing town of Kampala itself, with its street lighting, its sewage disposal, its public park, and its gracious and generally clean streets where the homes of wealthy Asians and the bungalows of European civil servants looked out from superb gardens to the Kampala hills (Apter 1997).
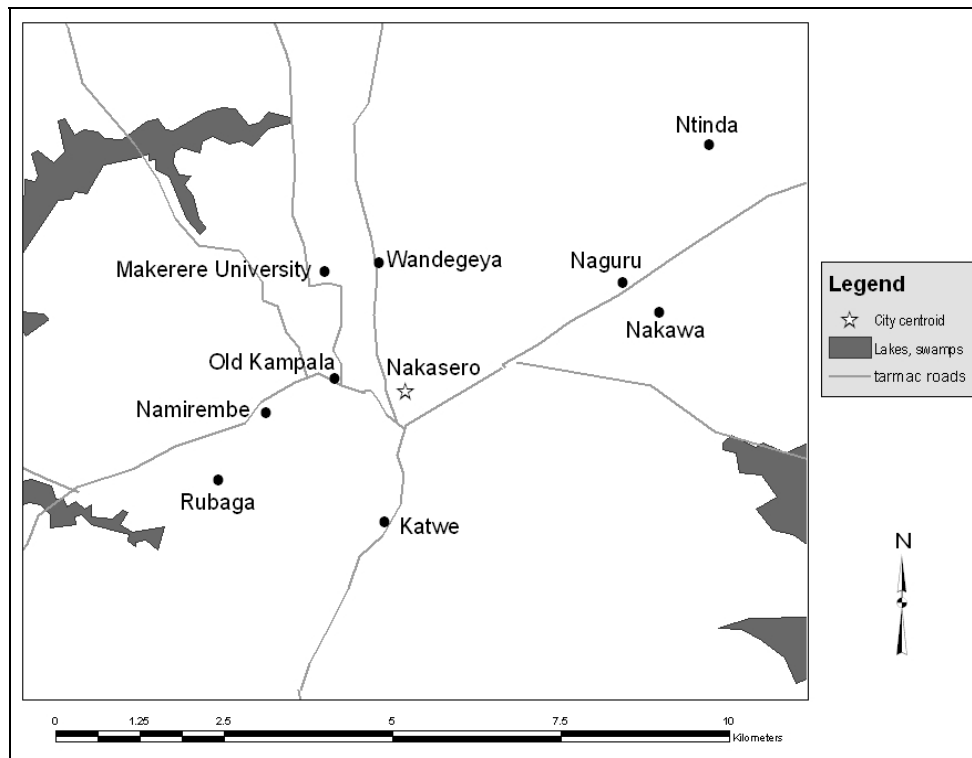
Fig. 2.2 Map of Kampala showing locations of places explained in the text about the urban formation.

2.1.4.5. Development of housing estates in east Kampala

There are three housing estates for Africans in east Kampala which were planed by the Ugandan Government in 1945: Naguru, Nakawa and Ntinda. Nakawa was designed for the lower wage groups, the more unskilled and temporary workers, and Naguru and Ntinda were for the higher paid and more skilled categories (Fig 2.2). The occupation began at Naguru and Nakawa during 1950 and at Ntinda more recently (Southall 1957). Now new estates based on the development plan can be observed at farther away and at several directions from city centroid.

2.2. Material and methods

2.2.1. Study sites

Two study sites, Kampala, the capital city of Uganda, and Kamuli were selected for this study (Fig 2.3). In the Kampala economic zone, the urban city area has become larger than the administrative boundary of Kampala District and now it consists of Kampala and a part of Mukono and Wakiso Districts. Nakasero was selected as the city centroid of the Kampala economic zone in this study because Nakasero Hill is the administrative centre of Kampala, and also the area lower than Kampala Road is the business centre. The Global Positioning System (GPS) location of Nakasero used for this study was recorded at latitude 0.31573 north and longitude 32.57726 east.

Kamuli economic zone was selected as the rural control to the urban and peri-urban areas of the Kampala economic zone, because it is far enough from Kampala, and it is not directly influenced by urbanisation of the capital city. Kamuli Town centre was located at latitude 0.94511 north, longitude 33.12374 east, and approximately 100 km northeast of Kampala. Kamuli is a small rural town in the Busoga Kingdom.
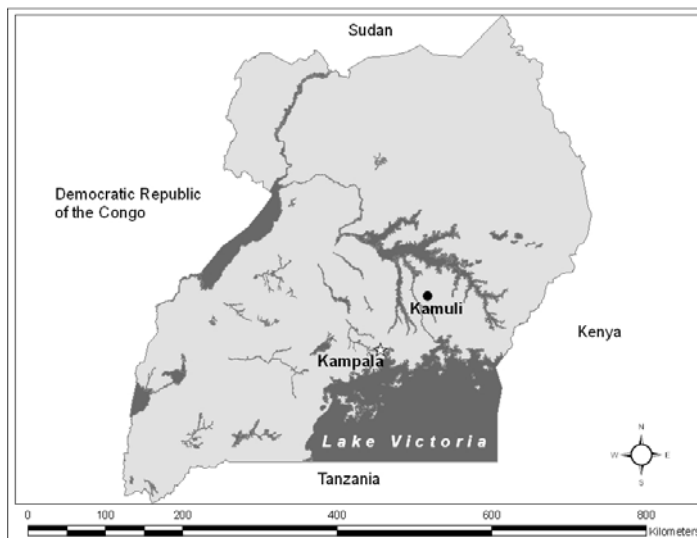
Fig. 2.3 Map of Uganda showing locations of Kampala and Kamuli

2.2.2. Sampling methods

2.2.2.1. Kampala economic zone

LC3s selection

In April 2005, prior to the field survey, Kampala was visited. By observation along tarmac roads, the areas within 5km from the Kampala city centroid clearly had urban features and the areas farther than 20km had rural features. Therefore the areas between 5 and 20 km radii circles from the Kampala city centroid were selected to be studied. Stratified random sampling was used to determine the sampling frame. Strata were LC3s (Sub-Counties), and sampling units were LC1s (Villages). Fig 2.4 shows the criteria of LC3 selection in the Kampala economic zone. All the LC3s completely contained in the areas between 5 and 20 km radii circles from the city centroid were selected (LC3s B).
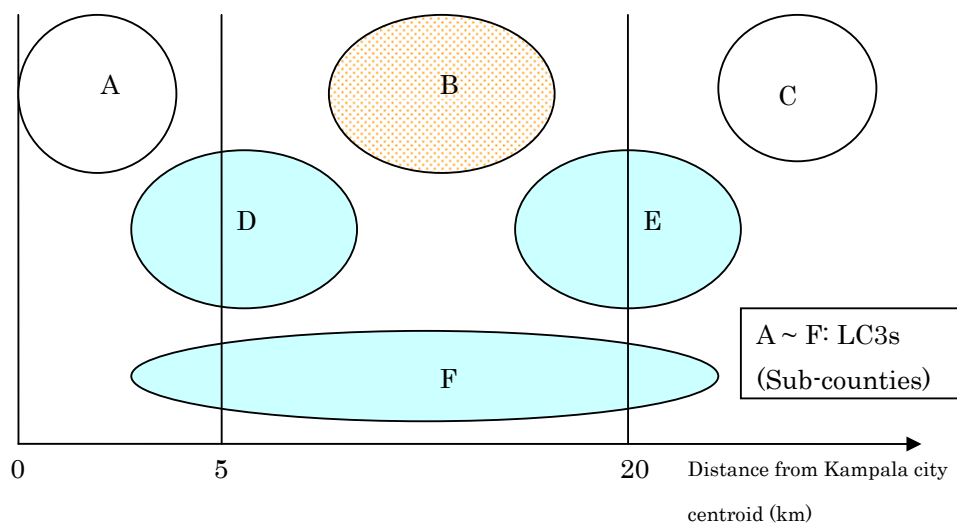
Fig. 2.4 Conceptual figure of LC3s selection in the Kampala economic zone. All the LC3s B were selected (highlighted with dots). The LC3s D, E and F which more than a half of the consisting LC1s were located in the area between 5 and 20 km radii from city centroid were selected. The rest of LC3s D, E, F and all the LC3s A, C were excluded from the study.

For the LC3s intersected by either the 5 or 20 km radii circle lines (LC3s D, E) or both of these lines (LC3s F), the LC3s which more than a half of the consisting LC1s were located in the areas between 5 and 20 km radii circles from the city centroid were selected, and the LC3s which less than a half of the consisting LC1s were located in the areas were excluded from this study. The lists of LC1s in Kampala District were obtained from the bulletin for a national vote in 2002 kept in the Nakawa Division Office in Kampala District, and the lists in Wakiso and Mukono Districts were from their District Electoral Commission Offices.

LC1s selection

For LC1 selection, the sample size was calculated using Epi info version 3.3.2. Expected proportion of LC1s with peri-urban features was set as 50 % so that necessary sample size would be the largest, because the proportion of LC1s with peri-urban features could not be estimated at all. Absolute precision and confidence interval were set as ±10 % and 95 % respectively.

After determination of the sample size, proportional allocation was used to determine the sample size in each stratum according to the number of sampling units in it. For the random sampling, the LC2s were arranged in alphabetical order in each LC3 at first, and then LC1s were also done within each LC2 in the same way. All LC1s in each LC3 were numbered in the order. Random numbers, generated in Microsoft Excel, were used to allocate the LC1s.

2.2.2.2. Kamuli economic zone

LC3s selection

Fig 2.5 shows the criteria of LC3 selection in the Kamuli economic zone. A ten kilometre radius circle was used instead of 20 km because most of the areas within 10km radius from Kamuli town centre apparently looked as rural features at the first visit to Kamuli in April 2005. Kamuli Town Council (LC3) was excluded from this selection as large part of the LC3 looked to have urban features. All the LC3s G and H were selected. The LC3s I which more than a half of the consisting LC1s were located in the areas between the Kamuli Town Council boundary and 10 km radius circle from the Kamuli Town centroid were selected. The LC3s I that less than a half of the consisting LC1s were located in the areas were excluded from the study. Kamuli District Electoral Commission Office was visited to obtain the list of LC1s.
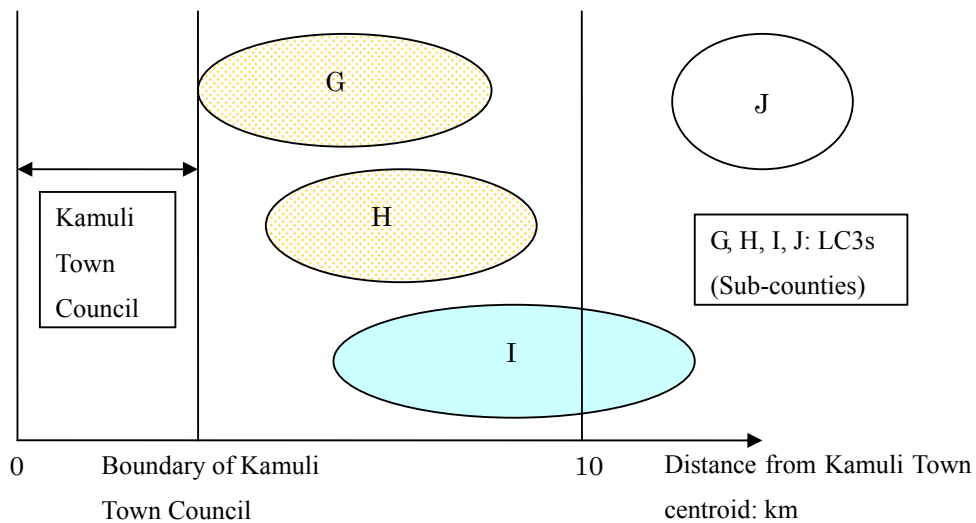
Fig. 2.5 Conceptual figure of LC3 selection in the Kamuli economic zone. All the LC3s G and H were selected. The LC3s I which more than a half of consisting LC1s were located in the areas between the boundary of Kamuli Town Council and 10 km radius circle from the town centroid were selected. The rest of LC3s I and LC3s J were excluded from the study.

LC1s selection

Similarly to the Kampala economic zone, the sample size was calculated using Epi
Info version 3.3.2. Expected proportion of LC1s with peri-urban features was set as
10 %, as most of LC1s were thought to have rural features. Absolute precision and
confidence interval were set as ±10 % and 95.0 % respectively. Then, proportional
allocation was performed.

2.2.3. Development of the questionnaire

Box 2.1 shows the contents of the questionnaire used for this study (shown in full in Appendix I). The questions regarding sociological and agricultural information were selected from indicators of peri-urban settlements found by Adam (2001) and Dreshel *et al*. (1999).

A pilot survey was carried out in three LC1s in Jinja District on 21st September 2005 to practice to work with local society. Speed of population change and direction of migration were added to the questionnaire after starting the Village Characteristic Survey when they were found to be the factor to determine level of urbanicity of LC1s (Box 2.1, described in details in section 2.3.2).

The number of households was asked to show the population density and to analyse factors related to peri-urbanicity. The area data of parishes (LC2s) were obtained separately from Uganda Bureau of Statistics (UBOS) to calculate the number of households per square kilometre. Number of full-time farming households was asked to show the relationship between agriculture and peri-urbanicity. For the purpose of finding the cost of transportation from peri-urban LC1s to Kampala city centre by public means, transportation cost to Kampala Taxi Park in Uganda Shillings was prepared in the questionnaire. The question about the distance to the nearest trading centre was prepared to compare the convenience of the life among urban, peri-urban and rural and it was asked as walking time in minutes to the nearest trading centre.

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Box 2.1 Contents of the interviews with the LC1 leaders

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1. Sociological information

Total number of households

Households of full-time farmers

Cost of transportation to Kampala city centre by public means

Distance to nearest trading centre

Provision of public facilities

Recent improvement of public facilities (less than 5 years) and year if yes

The number of ongoing land disputes between old residents and new comers, agricultural and non-agricultural use.

The number of schools

Perception of pollution (no, yes, very much)

Speed of population change

Direction of migration (from village or city)

</td>
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2. Agricultural information

The numbers of tomato, cooking banana, maize, rice, green vegetable farmers

The numbers of those farmers who sell to markets in Kampala

The numbers of those farmers who sell to nearby trading centre

Destination of the products

Purpose of their farming

The numbers of large scale crop and vegetable farmers who have more than 10 acres land

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Provision of public facilities (road light, piped water supply, sewage pipe and garbage collection), recent improvement (within 3 years) of them and the year of improvement were prepared to find the indicator of the PUI. The question for provision of electricity was prepared as existence of shops selling cold soda. As electricity was thought to be brought to rural by the private sector, the year of recent provision of electricity by the public sector was not asked. The numbers of ongoing land disputes between old residents and new comers, and between agricultural and non - agricultural use and the numbers of schools (public and private primary, public and private secondary) were prepared to examine the similarity of peri-urban areas in

Kampala to the peri-urban areas in Kumasi, Ghana (Adam 2001), where settlements have significantly more land disputes and junior secondary schools than other areas. The perception of pollution was prepared in rank (0: no, 1: yes, 2: very much) to test whether peri-urban areas are polluted the most. Agricultural information was prepared for characterisation of urban and peri-urban agriculture described in Chapter 3, however it was used in this chapter to support the urbanicity classification of LC1s.

2.2.4. Village Characteristic Survey (VCS)

The VCS was conducted using a questionnaire at 87 LC1s in the Kampala economic zone, and 30 LC1s in the Kamuli economic zone from 23rd September to 8th November, 2005. As far as possible, the LC1 leaders and other committee members were interviewed together. If the LC1 leader was not available, and other committee members could not answer the questions, the LC1 leader was contacted later by mobile phone or direct revisit. The official language in Uganda is English, however it is not widely spoken in rural areas. In the Kampala economic zone, the main language was Luganda and in Kamuli, Lusoga. In both study sites, a translator was employed. As Luganda and Lusoga are similar languages, both studies were assisted by the same translator. In addition to the interview, observed aspects, for example formation of trading centre, features of dominant buildings and vegetation were recorded. As the determinant factors of level of urbanicity, speed of population change and direction of migration were discovered during the VCS (described in section 2.3.2), the LC1s which were visited before the discovery were revisited for the questions relevant to the factors.

2.2.5. Geographical data

The LC1 locations were recorded with a hand-held Global Positioning System (GPS, Garmin, Olathe, KS, USA). All GPS readings were taken at the LC1 office or the village leader's residence where interviews were performed. These LC1 locations were entered into EXCEL spread sheet (Microsoft Office XP, Redmond, USA), and were saved as DBF4 file. Euclidean (straight line) distance between the city centroid and each LC1 was calculated using ArcView version 3.1 Geographic Information System (ESRI Systems, Redlands, CA, USA). Geographical data of LC2 boundaries and areas, and other shape files were obtained from Land and Surveys Department, Ministry of Land Housing and Urban Development of Uganda.

The National Biomass Study, from which the spatial data layers were obtained, is provided by the Universal Transverse Mercator (UTM) projection, with the detailed parameters as shown in Box 2.2. GPS data were collected in latitude/longitude format, in the WGS 84 datum, and were converted to the Biomass projection for processing of maps (Uganda Forest Department 1996). Maps were produced using ArcGIS 9 Geographic Information System (ESRI Systems, Redlands, CA, USA).

Box 2.2 The Biomass Projection	
Map projection	Transverse Mercator
Spheroid	Clarke 1880
Central meridian	33
Reference latitude	0
Scale factor	0.9996
False Easting	500,000
False Northing	200,000

2.2.6. Land price

Land price information was collected to test whether it drops dramatically in peri-urban areas as Cavailhes & Wavresky (2003) reported in France. Land prices of sample LC1s in the Kampala economic zone in 2004 were investigated from the land transaction records at the Valuation Division of the Ministry of Water, Land and Environment, Uganda.

2.2.7. Classification of level of urbanicity

As ready-made criteria for urbanicity classification of LC1s were not available, a decision tree model was developed during the VCS (shown in the results section 2.3.3). The level of urbanicity of LC1s was judged according to this decision tree model. Agricultural data and observation data, and the records of observation of LC1s were used for supporting classification. The tree model developed was tested for its validity using tree model function with statistic software, R 2.4.1.

2.2.8. Definitions of urbanicity and development types

Box 2.3 shows the definitions of levels of urbanicity and development types of LC1s. The definitions were determined based on the findings on people's flow seen in urbanisation (section 2.3.2). LC1s were classified into three levels of urbanisation: urban, peri-urban and rural, and into eight development types: city centre, high and middle income residential areas, slum, trading centre, University/institution, peri-urban and rural.

Box 2.3 Definitions of levels of urbanicity and development types of LC1s

Levels of urbanicity

Urban:

Densely populated areas; the percentage of full-time farming household is 0 to low, and the main agricultural activity is backyard farming in small plots.

Peri-urban:

Transition areas from rural to urban; the percentage of full-time farming household is low to high, the speed of population increase is high, migration is from city or town by house construction, and there is still space for crop cultivation.

Rural:

Static areas before urbanisation starts; the percentage of full-time farming household is high, speed of population increase is slow and the main source of the increase is reproduction.

Development types

City centre: Dominated by business buildings.

High income residential area: Large luxurious houses with high fence.

Slum area: Crowded by low income residents, characterised by mud wall houses.

Middle income residential area: Residential area between above two types.

Trading centre: Trading market with shops and restaurants along a road.

University/institution: whole area of the LC1 is occupied with a university, or an institution.

Peri-urban: Rapid population increase due to the migration from the city or town by house construction.

Rural: The population change of peri-urbanisation has not started yet.

2.2.9. Statistical analysis

2.2.9.1. Contributions to the determination of urbanicity level

The degrees of the contribution of factors: percentage of full-time farmer, speed and the source of population change and agricultural and observational data, to the determination of level of urbanicity were analysed using the tree-based model function rpart (Venables 2002) with statistic software R 2.4.1. The data obtained from all LC1s interviewed in the Kampala economic zone were used for the test. Percentage of full-time farmer, speed and the source of population change were used in the computed model. The observational data, dominance of mud wall house and agricultural data, cultivation type, were not used as inputs for the computed model since they were not necessarily recorded at all the LC1s; mud wall domination was recorded only in the slum LC1s, and cultivation type was interviewed only in the 24 LC1s which needed to be differentiated between middle income residential and peri-urban areas. Complexity parameter analysis (Venables 2002) was also applied using complexity parameter function with statistic software R 2.4.1 to show the degrees of contribution of factors used in the computed tree model.

Finally, to assess the contribution of agricultural and observational data to the determination of level of urbanicity, the results of classification using three methods; 1) the developed decision tree model using agricultural and observation data, 2) combination of computed decision tree model and agricultural and observational data, and 3) developed decision tree model without using agricultural and observation data, were compared. For 2), the second splits of the computed tree model were followed by the developed tree model using observation data until all LC1s could be classified. Unclassified LC1s by developed tree model without agricultural and observation data

were left as unclassified. The 95% confidence intervals of the percentage of LC1s correctly classified were calculated using one-sample proportions test with R 2.4.1.

2.2.9.2. Socio-economic factors related to urbanicity

To find the socioeconomic factors related to urbanicity, the results of all socio-economic factors listed in the Box 2.1 (section 2.2.3) were compared among urban, peri-urban and rural LC1s. When a significant difference was found among three urbanicity groups, which means at least one group is significantly different, each two adjacent groups (urban and peri-urban LC1s, and peri-urban and rural LC1s) were compared.

Continuous data (number of households per square kilometre, Euclidean distance from city centroid, transportation cost to Kampala taxi park and land price) were tested using One-Way ANOVA with statistic software R 2.4.1. To calculate the number of households per square kilometre, at first areas of LC1s were calculated by dividing the LC2 (parish) area by the number of LC1s consisting the LC2, since area data at the LC1 level were not available. Data were checked for their normality in the probability distribution using Box-Cox transformations (Box 1964; Crawley 2002) with R 2.4.1 to estimate the transformation parameter λ (lambda). The data were transformed either by log (when $\lambda=0$), or λth power to the data (when $0<\lambda<1$) before performing One-Way ANOVA. The number of households per square kilometre and transportation cost to Kampala taxi park were log-transformed. Euclidean distance from city centroid was transformed with square root. Land price was transformed with the 0.2nd power. For back-transformation, exponential was applied for log transformed data, the second power for transformed data with square root, and the

fifth power for the 0.2nd power. A 95% confidence interval was obtained multiplying the quantiles of the *t* distribution in the degree of freedom by the standard error (**qt (0.975, df)*se**) using R 2.4.1 (Crawley 2002).

The time to nearest trading centre was analysed using a Generalised Linear Model (GLM) with quasipoisson errors in statistic software R 2.4.1 as it was count data containing many zeros and as the data was 'over-dispersed' (Crawley 2002). As quasipoisson uses log-link, obtained results were back-transformed using exponential (Crawley 2002). The perception of pollution in rank (0: no pollution, 1: feel pollution, 2: feel pollution very much) was tested using Kruskal-Wallis Test in MINITAB 14.1.

The percentage of full-time farming households, the percentage of LC1s having land disputes between old residents and new comers, land disputes between agriculture and non-agriculture sectors, public and private schools and public facilities such as road light, piped water supply, sewage pipe, garbage collection, electricity and recent improvement of public facilities were compared among urban, peri-urban and rural LC1s using Chi-square test with R 2.4.1. A 95% confidence interval was calculated for all of the percentages using Chi-square test with one proportion using R 2.4.1. In the questionnaire, the number of land disputes were asked, however many LC1s did not have land disputes, and even in the LC1s with land disputes, there were a few of them. Therefore the data were converted into binomial variables (no land disputes: 0, or there were land disputes: 1). Similarly, the number of schools were converted into binomial variables.

2.2.9.3. The relationship between distance from city centroid and sociological factors

Linear regression was used to examine the relationships between the distance from city centroid and log-transformed transportation cost and land price using statistic software R 2.4.1. The relationships between distance from city centroid and the proportion of LC1s with public facilities were analysed using a GLM with binomial error in statistic R 2.4.1. Fitted prediction and 95% confidence interval lines of the relationship between proportion of LC1s having the facilities and the distance from city centroid were obtained using the model (Appendix II: code for R).

2.3. Results

2.3.1. Selected samples

2.3.1.1. Kampala economic zone

Selected LC3s

Fig 2.6 shows 10 LC3s selected in the Kampala economic zone: Kawempe and Nakawa Division in Kampala District, Kira, Makindye, Nabweru, Nangabo, Nsangi, Ssisa, Wakiso Sub-Counties in Wakiso District, and Goma Sub-County in Mukono District.
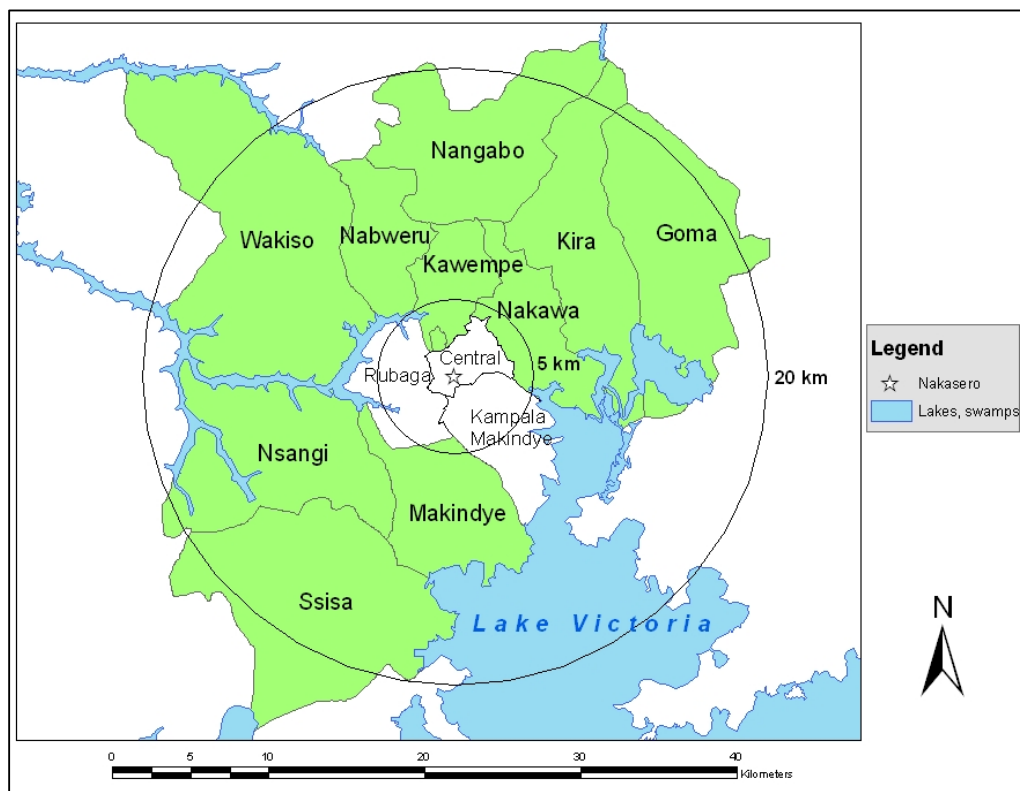
Fig. 2.6 Map of selected LC3s in Kampala economic zone; Kawempe and Nakawa Division in Kampala District, Kira, Makindye, Nabweru, Nangabo, Nsangi, Ssisa, Wakiso Sub-Counties in Wakiso District, and Goma Sub-County in Mukono District were selected.

Selected LC1s

In the Kampala economic zone, 87 villages (LC1s) were selected (Table.2.1). Initially, calculated necessary sample size was 86. After rounding off their proportions in each stratum to the integer point, the total number of LC1s became 87.

Table. 2.1 The sample LC1s in the Kampala economic zone

No.	Strata (LC3s)	Districts	Number of LC1s	Sample size (LC1s)
1	Kawempe	Kampala	119	13
2	Nakawa	Kampala	277	30
3	Kira	Wakiso	40	4
4	Makindye	Wakiso	54	6
5	Nabweru	Wakiso	26	3
6	Nangabo	Wakiso	50	6
7	Nsangi	Wakiso	53	6
8	Ssisa	Wakiso	62	7
9	Wakiso	Wakiso	73	8
10	Goma	Mukono	36	4
Total	10	3	790	87

2.3.1.2. Kamuli economic zone

Selected LC3s

In Kamuli, 3 LC3s, Butansi, Kitayunjuwa and Nabwigulu were selected (Fig 2.7).
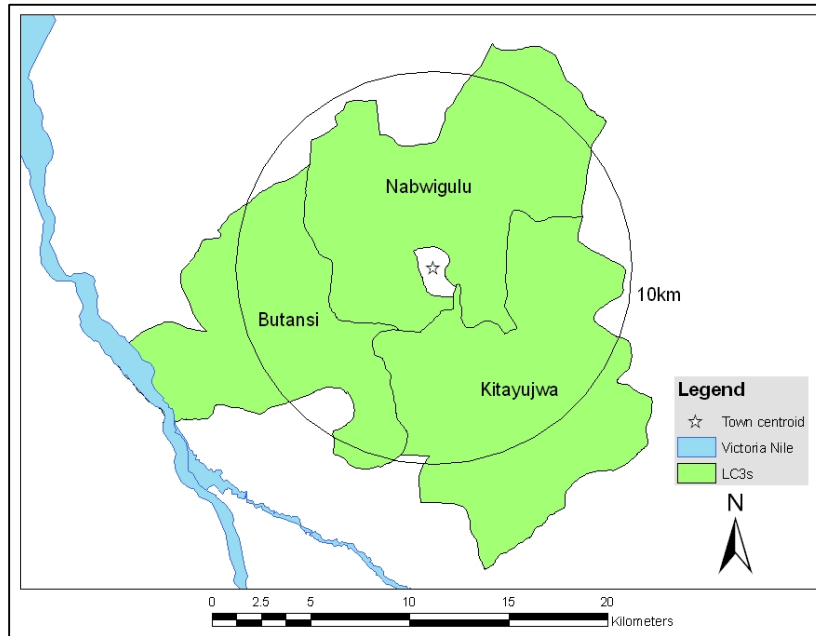
Fig. 2.7 Map of selected LC3s in Kamuli District; Butansi, Kitayunjuwa and Nabwigulu Sub-counties

Selected LC1s

In Kamuli, 30 out of 220LC1s were selected (Table.2.2).

Table. 2.2 The sample LC1s in Kamuli local economic zone

No.	Strata (LC3s)	LC5s (Districts)	Number of LC1s	Sample LC1s
1	Butansi	Kamuli	48	7
2	Kitayunjwa	Kamuli	118	16
3	Nabwigulu	Kamuli	54	7
Total	3	1	220	30

2.3.2. People's flow seen in urbanisation

Fig 2.8 shows a common rule of people's flow in urbanisation discovered during the interviews with LC1 leaders. The rule was applicable to all LC1s both in the Kampala and Kamuli economic zones. This finding was used to develop a decision tree model of urbanicity classification of LC1s. The flow starts from rural areas as migration from rural areas to trading centres and slum areas in urban areas. The migrants live in small and cheap rental rooms because these are most affordable options for the new comers. When people successfully find a job to earn enough wages to escape there, they move to better renting rooms in urban residential areas or peri-urban areas by purchasing a plot to construct a house. Rich urban residents also move to peri-urban areas by purchasing a bigger land and house. This is how the city grows.

The dynamics in time and space are the greatest in peri-urban areas as Adam (2001) described. At first rural area is static in terms of population change. As if there is a strong gravity of urbanization, when the rural area changes to peri-urban area, the wave of house construction and the migration from the city reaches there, and the speed of the population change becomes the highest. The speed will be slow again when most of the agriculture fields are replaced with houses; transformed into urban residential areas. Population does not increase in trading centres as well when the population density becomes the maximum. Such trading centres are still receiving immigrants from rural but at the same time, sending earned people out to residential and peri-urban areas.

Peri-urban area

Urban residential area

Trading centre

Slum

Rural
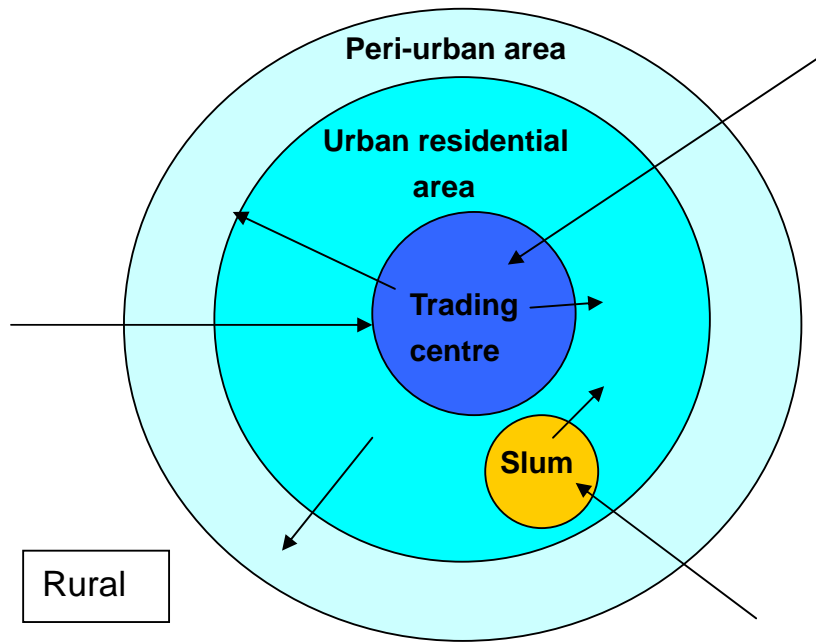
Fig. 2.8 Conceptual figure of people's flow seen in urbanization

2.3.3. Decision tree model for urbanicity classification

Fig 2.9 shows the decision tree model for urbanicity classification developed based on the rule of the people's flow seen in the urbanization (Fig 2.8). It enabled simple and explicit classifications of level of urbanicity of the LC1s and their development types.

In Fig 2.9, the classification process starts from calculation of the percentage of full-time farming households. The next question is the source of the population increase, and the process continues downward of the model. For example, a LC1 that the percentage of full-time farmer is 0, and main source of population change is business building construction (in this case population is decreasing), is classified as urbanicity; urban, and development type; city centre. Another example: a LC1 that the percentage of full-time farmer is 48, main source of population change is migration by construction of house from city and the speed of change is rapid, and there is still land for cultivation, is classified as urbanicity; peri-urban, and development type; peri-urban. The development types, urban high or middle income residential area of LC1s were judged by observing whether luxury large houses with high fences are predominant or not.

Fig. 2.9 Decision tree model for urbanicity classification

Inside the figure:

Q: Percentage of full-time farmer?

<50 (%) ≧50 (%)

<50 (%) branch:
Q: What is the main source of population increase?

- Business building construction (population decreasing) → Urban city centre
- Migration from village to rental rooms → Q: Mud wall house dominating?
  - Yes → Slum
  - No → Urban trading centre
- Migration from town by house construction → Q: Cultivation type, speed of population increase?
  - Backyard farming, fast and slow → Urban high or middle income residential area
  - More land, fast → Periurban

≧50 (%) branch:
Q: What is the main source of population increase?

- Migration from village to rental rooms → Q: Many migrants from larger town by house construction as well?
  - Yes → Periurban trading centre
  - No → Rural trading centre
- Migration from town by house construction → Q: Speed of population increase?
  - Fast → Periurban
  - Slow → Rural
- Reproduction → Rural

2.3.4. Classification of LC1s into urban, peri-urban and rural groups in Kampala and Kamuli economic zones

Table 2.3 and 2.4 show the results of the classification of 87 LC1s in the Kampala economic zone and 30 in the Kamuli economic zone. In Kampala economic zone, out of 87 LC1s, 59LC1s were classified into urban (67.8%, 95% CI: 56.8-77.2), 11 were into peri-urban (12.6%, 95% CI: 6.8-21.9), and 17 were into rural (19.5%, 95% CI: 12.1-21.7), respectively. Middle income residential area was the most predominant development type and accounted for 37.3% (22 LC1s) of urban LC1s, and the second predominant type was trading centre (17 LC1s, 28.8%).

Table. 2.3 Level of urbanicity of the LC1s in Kampala economic zone

Development type	Urban	Peri-urban	Rural
City centre	1		
High income residential area	6 (4*)		
Middle income residential area	22		
Slum	6		
Trading centre	17	2	1
University/institution	7*		1*
Peri-urban		9	
Rural			15
Total	59	11	17
Percentage (%)	67.8	12.6	19.5

*Unable to conduct interviews

One of 17 rural LC1s (5.9%) was classified into university/institute because it was a prison. Twelve LC1s (11 urban LC1s and 1 rural LC1) were unable to be interviewed

as there were no residents (university/ institution), or houses were fenced and guarded in very high income residential areas. All adults were absent in a compound for doctors and nurses of a hospital in a middle income residential area LC1 and only speed of population change and direction of migration were asked to teen-agers. Therefore, socio-economic characteristics were analysed for only 74 LC1s (47 urban, 11 peri-urban and 16 rural LC1s).

In Kamuli economic zone, out of 30 LC1s, none was classified into urban (0%, 95% CI: 0.0-14.1), 2 LC1s were into peri-urban (6.7%, 95%CI: 1.2-23.5), and 28 were into rural (93.3%, 95%CI: 76.5-98.8). One of 2 peri-urban LC1s (50%) and 5 of 28 rural LC1s (17.9%) were trading centres (Table 2.4).

Table. 2.4 Level of urbanicity of LC1s in Kamuli economic zone

Development type	Urban	Peri-urban	Rural
City centre			
High income residential area			
Middle income residential area			
Slum			
Trading centre		1	5
University/institution			
Peri-urban		1	
Rural			23
Total	0	2	28
Percentage (95% CI)	0	6.7	93.3

2.3.5. Contributions of the factors to determination of urbanicity level

The degree of contribution of factors used in the decision tree model developed for urbanicity classification (Fig2.9, section 2.3.3) was assessed using a tree model function with R 2.4.1. Fig 2.10 shows the computed decision tree model. This computed model showed similar splits to the developed decision tree model and prioritised the percentage of full-time farmer the most. Left and right branch were swapped, and the split percentage of full-time farmer was 6.889%, far lower than 50% in the developed model. After the left branch, LC1s with rapid population change fell into peri-urban and slow change fell into rural. After the right branch, migration from city suggested urban residential area, and urban trading centres were receiving migrants from rural.
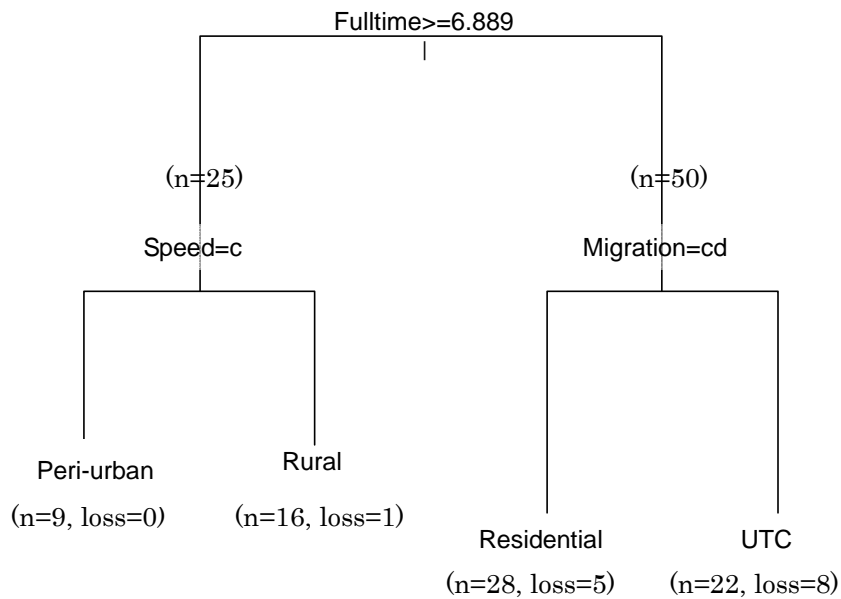
Fig. 2.10 Computed decision tree model for urbanicity classification (size=4).
Speed: (left) rapid, (right) no change, slow; Migration: (left) city, no migration, (right) both, building, reproduction and rural.
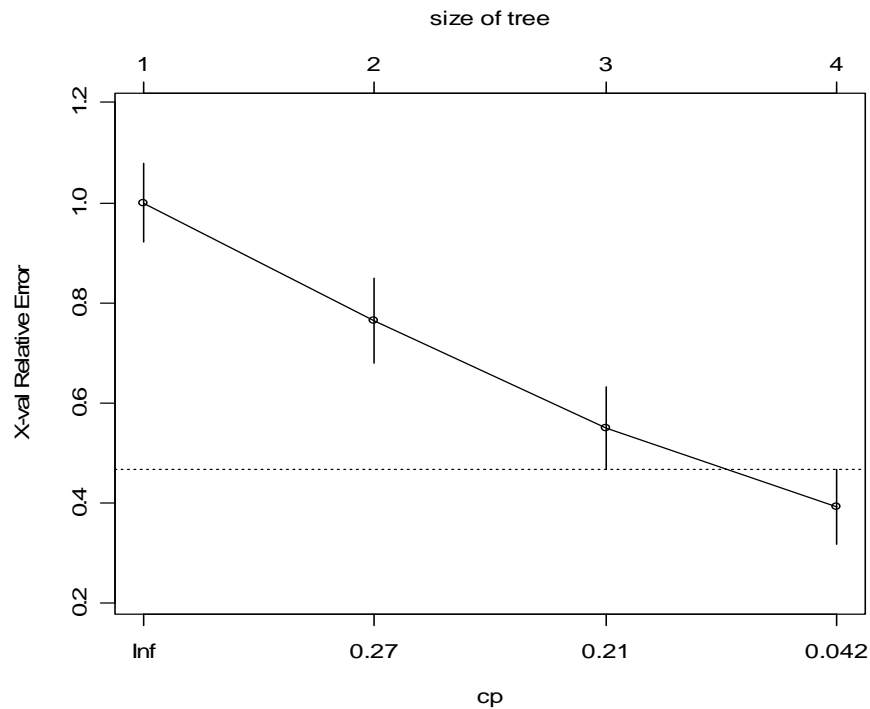
Fig. 2.11 The relative errors and complexity parameter (CP) according to the size of the tree. Size 1 is with no split, size 2 is with the first split, size 3 with 2nd left split and size 4 with 2nd right split of the computed model. The vertical lines on the relative errors show 1-standard deviations from the means. The percentage of full-time farmer and speed of population change contributed largely (decrease of relative error: 0.24 and 0.22 respectively). Source of the population change decreased relative error by 0.16.

The computed model prioritised speed of population change (the second left split) the second and source of the population change (the second right split, migration, Fig 2.10). Complexity parameter analysis showed the degree of contribution of factors to the determination of urbanicity level (Fig 2.11). The percentage of full-time farmer and speed of population change contributed largely (relative error decreased by 0.24 and 0.22 respectively) and source of the population contributed slightly less (relative error decreased by 0.16).

Table. 2.5 Comparison of the methods of urbanicity classification

Classification	1) Developed model using agricultural, observation data	2) Computed model using agricultural, observation data	3) Developed model without agricultural & observation data
City centre	1	1	1
Residential area	24	23	17
Slum	6	6	6
Trading centre	17	13	8
Peri-urban	11	11	11
Rural	16	16	16
Correctly classified (%: CI)	75 -	70 (93.3: 84.5-97.5)	59 (78.7: 67.4-87.0)
Misclassified	0	3	3
Not classified	0	2	13

Table 2.5 shows the comparison among three methods; 1) the developed decision tree model using agricultural and observation data, 2) combination of computed decision tree model and agricultural and observational data, and 3) developed decision tree model without using agricultural and observation data. Regarding all the classification with the model developed in the present study correct, the method 2) could classify 93.3% (95% CI: 84.5-97.5) of LC1s correctly. Three LC1s were misclassified because those LC1s were atypical. Two trading centre LC1s received migrants not from rural but from city centre areas, therefore they were misclassified into urban residential area. These trading centres were close to peri-urban areas of

Kampala, and there were a lot of house construction by city residents. A small LC1 in an urban residential area was receiving migrants from rural, and misclassified into trading centre (people's flow seen in urbanisation was explained in section 2.3.2).

On the contrary, the model 3) could classify 78.7% of the LC1s correctly. This lower percentage was due to the 13 LC1s unable to be classified without agricultural and observation data. In 5 out of these 13 LC1s, the source of the population change was migration from both city and rural areas, and in 6 urban LC1s, population was not changing because the spatial capacity was full. The population change data was missing in an urban LC1 and population was increasing slowly by reproduction (rural character) in an urban trading centre LC1 with almost full spatial capacity. All LC1s misclassified or unable to be classified were urban residential and urban trading centre type.

2.3.6. Spatial distribution of urban, peri-urban and rural LC1s

Spatial distributions of classified urban, peri-urban and rural LC1s in Kampala economic zone is shown in Fig 2.12. In Kampala, city centroid, Nakasero was surrounded by urban LC1s, and as the distance from city centroid increases, the level of urbanicity decreased to peri-urban and rural. Euclidean distance (km) was significantly short in urban (6.4, 95%CI: 4.7-8.7), middle in peri-urban (12.1, 95%CI: 10.5-13.9; urban and peri-urban: $F=25.34$, $df=1$, error=68, $p<0.001$), and long in rural (17.0, 95%CI: 14.6-19.7; peri-urban and rural: $F=19.55$, $df=1$, error=29, $p<0.001$, Table 2.7). The range of the distance of peri-urban LC1s was between 8.2
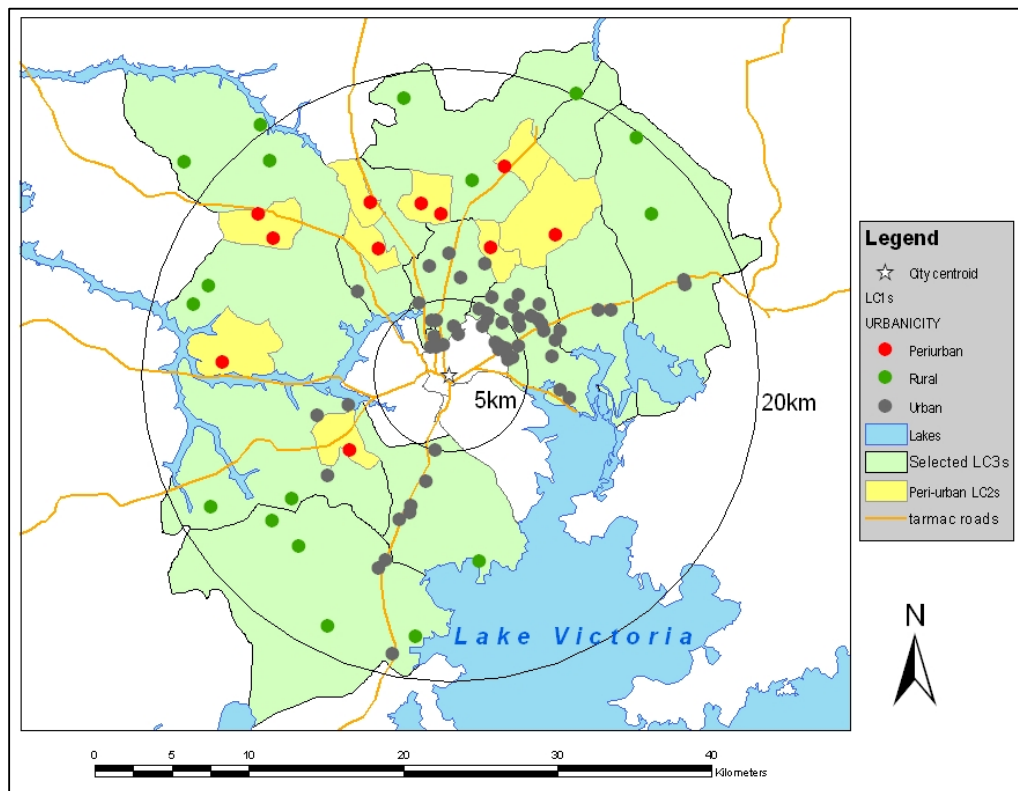
and 16.2 km.

Fig. 2.12 Map of urban, peri-urban and rural LC1s in Kampala economic zone. The mean distance from city centre to peri-urban LC1s was 12.6km (95%CI: 7.9-20.0). Yellow areas are parishes (LC2) containing peri-urban LC1s.

Fig 2.13 shows the development types of urban LC1s. Among urban LC1s, slums were located close to the city centroid. High income residential areas (Naguru, Ntinda) were concentrated on the northeast of the city centroid. Slum areas, high income residential areas and a middle income residential area (Nakawa) were intact for a long time as described in the literature (refer to section 2.1.5.4 Formation of slum areas and section 2.1.5.5 Development of housing estates). The predominant types of LC1s, trading centres and middle income residential areas were geographically distributed in mixture in urban areas.
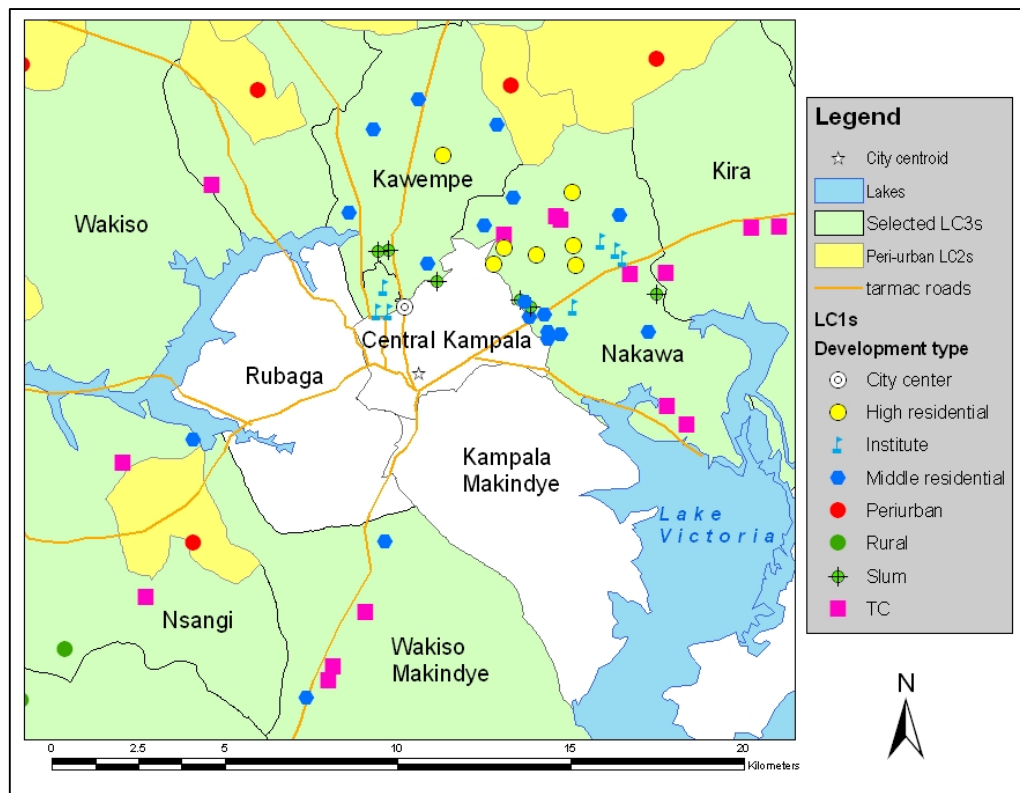
Fig. 2.13   Development types of urban LC1s in the Kampala economic zone.

Fig 2.14 shows the spatial distribution of peri-urban and rural LC1s in Kamuli economic zone. In Kamuli, 2 peri-urban LC1s were located at 0.8km and 1.7km from the town centre (mean 1.3km), and the other rural LC1s surrounded them.
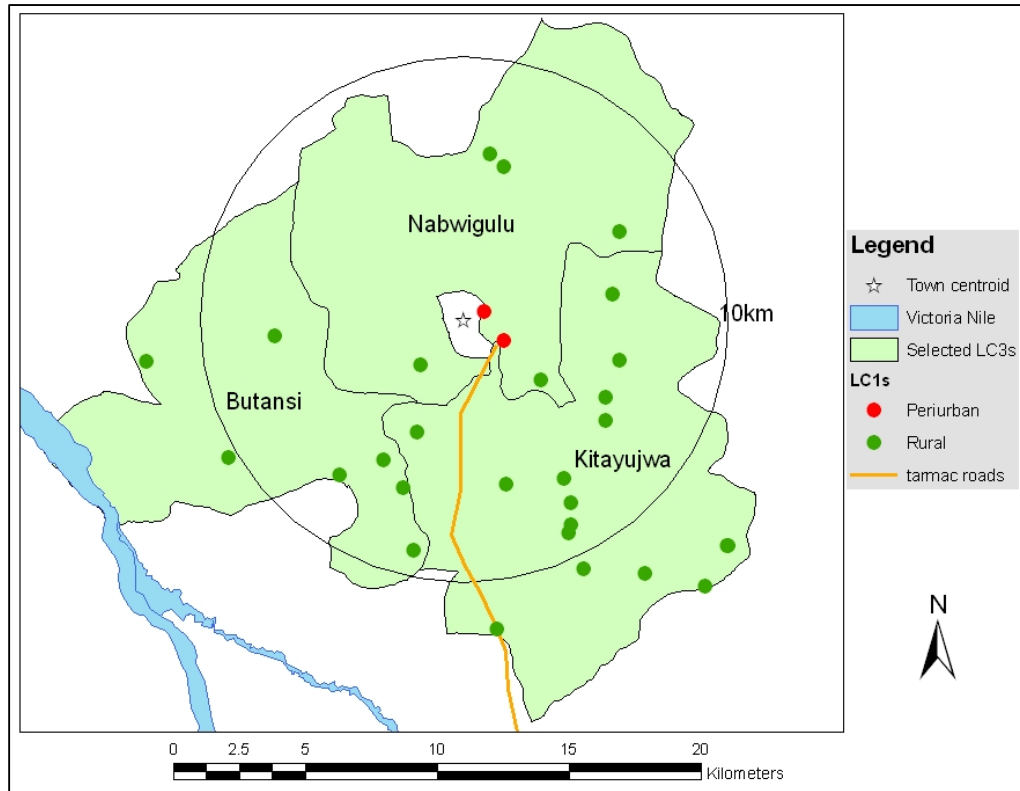
Fig. 2.14 Spatial distribution of peri-urban and rural LC1s in the Kamuli economic zone

2.3.7. Socio-economical characteristics of urban, peri-urban and rural areas

Table 2.6 shows the numbers of LC1s and households interviewed in both the Kampala and Kamuli economic zone. For the purpose of comparison of the three levels of urbanicity, socio-economic factors were discussed only for Kampala economic zone, as it included all of urban, peri-urban and rural LC1s.

Table. 2.6 Number of households in the interviewed LC1s

	Kampala			Kamuli	
	Urban	Peri-urban	Rural	Peri-urban	Rural
Interviewed LC1s	48	11	16	2	28
Households	36,184	5,294	3,484	420	3,572

Table 2.7 shows the continuous and ranked data. There were significant differences among urban, peri-urban and rural LC1s in the number of households per square kilometre (F=46.04, df=2, error=72, $p<0.001$), Euclidean distance from city centroid (F=49.43, df=2, error=84, $p<0.001$), transportation cost to Kampala Taxi park (F=39.58, df=2, error=70, $p<0.001$), time to nearest trading centre ($p<0.001$), perception of pollution in rank (H=15.56, df=2, $p<0.001$), and land price (F=27.43, df=2, error=63, $p<0.001$, test statistics among three groups were not shown in Table 2.7 and between each two groups shown).

Table. 2.7 Socio-economic factors related to urbanicity (continuous and ranked data)

Factor	n (urban, peri-urban, rural)	Mean with 95%CI (m: median)			Test statistics	p-value
		Urban	Peri-urban	Rural		
Number of households/ km^2 (log)	48, 11, 16	3.0±1.0	2.2±0.7	1.8±0.6	UP: F$_{1, 57}$=21.37	p<0.001
Back-transformed: number/ km^2		1047(96-11,481)	174 (39-776)	62 (16-240)	PR: F$_{1, 25}$=13.56	p=0.001
Distance from city centroid (m,sqrt)	59, 11, 17	80.0±11.3	110.2±7.9	130.5±9.7	UP: F$_{1, 68}$=25.34	**p<0.001**
Back-transformed: km		6.4 (4.7-8.3)	12.1(10.5-13.9)	17.0(14.6-19.7)	PR: F$_{1, 26}$=19.55	**p<0.001**
Transportation cost to Kampala (log)	47, 11, 15	6.3±0.2	6.7±0.2	7.2±0.3	UP: F$_{1, 56}$=13.29	**p<0.001**
Back-transformed:Uganda Shillings		545 (446-665)	812 (665-992)	1339(992-1808)	PR: F$_{1, 24}$=15.93	**p<0.001**
Time to nearest trading centre (log)	48, 11, 16	2.2±1.2	1.8±1.2	3.4±1.3	UP:	**p=0.488**
Back-transformed: minute		9.2 (2.8-30.2)	6.1 (1.8-20.7)	28.7(8.2-100.6)	PR:	p=0.010
Perception of pollution (rank:0-2)	48, 11, 16	m: 1.0	m: 1.0	m: 0.0	H$_2$=15.56	**p<0.001**
Land price (0.2nd power)	42, 11, 13	61.3±5.6	49.1±5.5	44.2±7.3	UP: F$_{1, 51}$=19.66	**p<0.001**
Back-transformed: million		866 (536-1340)	285 (158-485)	169 (68-362)	PR: F$_{1, 22}$=2.11	
Uganda Shillings/ acre						p=0.16

UP: between urban and peri-urban, PR: between peri-urban and rural, sqrt: square root

The number of households per square kilometre was analysed using log transformed data. The mean number of households per square kilometre in urban LC1s (1047, 95%CI: 96-11,481) was significantly larger than in peri-urban LC1s (174, 95%CI: 39-776, F=21.37, df=1, error=57, $p<0.001$), and the number in peri-urban LC1s was significantly larger than in rural LC1s (62, 95%CI: 16-240, F=13.56, df=1, error=25, $p=0.001$). Euclidean distance from city centroid was analysed using transformed data with square root, and the results were explained in section 2.3.6.

Transportation cost in Uganda Shillings to Kampala Taxi Park was analysed using log-transformed data. The mean transportation cost in urban LC1s (544, 95%CI: 446-665) was significantly higher than peri-urban LC1s (812, 95%CI: 665-992, F=13.29, df=1, error=56, $p<0.001$) and the mean cost in peri-urban LC1s was significantly higher than in rural LC1s (1339, 95%CI: 992-1808, F=15.93, df=1, error=24, $p<0.001$). The mean time (minutes) to the nearest trading centre on foot was not significantly different between urban (9.2 (95%CI: 2.8-30.2)) and peri-urban LC1s (6.1 (95%CI: 1.8-20.7), $p=0.488$), but in rural LC1s (28.7 (95%CI: 8.2-100.6), $p=0.010$), it took significantly longer than in peri-urban LC1s.

The mean rank of perception of pollution was significantly higher in urban and peri-urban LC1s (1.0 (1: feel pollution)) than in rural LC1s (0.0 (0: none), H=15.56, df=2, $p<0.001$).

Land price data was transformed using the 0.2nd power for the analysis. Mean land

price in urban LC1s (866, 95%CI: 536-1340) was significantly higher than in peri-urban LC1s (285, 95%CI: 158-485, F=19.66, df=1, error=51, $p<0.001$), but the mean price in peri-urban LC1s was not significantly different from rural LC1s (169, 95%CI: 68-362, F=2.11, df=1, error=22, $p=0.160$).

Table 2.8 shows the percentages of full-time farming households in the studied urban, peri-urban, and rural LC1s. The percentages were significantly different among three groups ($x^2=18436.8$, df=2, $p<0.001$). The percentage in peri-urban LC1s (22.8%) was significantly higher than in urban LC1s (1.9%, $x^2=4560.0$, df=1, $p<0.001$), and lower than in rural LC1s (71.1%, $x^2=2016.1$, df=1, $p<0.001$).

Table. 2.8 The number of households and the percentages of full-time farming households in the studied LC1s

	Urban	Peri-urban	Rural
Total households	36184	5294	3484
Agricultural households	702	1205	2478
Percentage (95%CI)	1.9 (1.8-2.0)	22.8 (21.6-23.9)	71.1 (69.6-72.6)

Table 2.9 shows the binomial data. The proportion of LC1s with land disputes between old residence and new comer ($x^2=2.1$, df=2, $p=0.35$) or the proportion of LC1s with land disputes between agriculture and non-agriculture use ($x^2=6.0$, df=2, $p=0.05$) was not significantly different among three urbanicity groups. The proportions of LC1s having a public ($x^2=3.1$, df=2, $p=0.21$) and private primary school ($x^2=2.2$, df=2, $p=0.33$) were not significantly different among three urbanicity

groups. Public secondary schools were seen only in urban LC1s. The proportion of LC1s having private secondary school in peri-urban areas was not significantly different among three groups (x^2=5.4, df=2, p=0.07).

Table. 2.9 Socio-economic factors related to the level of urbanicity (binomial data)

Factors	Positive response (percentage with 95%CI)		
	Urban (n=47)	Peri-urban (n=11)	Rural (n=16)
Land disputes between old resident and new comers	11 (23.4:12.8-38.3)	4 (36.4:12.4-68.4)	2 (12.5:2.2-39.6)
Land disputes between agricultural and non-agricultural land use	7 (14.9: 6.9-28.9)	5 (45.5:18.1-75.4)	2 (12.5:2.2-39.6)
Public primary school	17 (36.2: 23.1-51.5)	7 (63.6:31.6-87.6)	8 (50.0:28.0-72.0)
Private primary school	26 (55.3: 40.2-69.5)	8 (72.7:39.3-92.7)	7 (43.8:20.8-69.4)
Public secondary school	3 (6.4: 1.7-18.6)	0 (0.0: 0.0-32.1)	0 (0.0: 0.0-24.1)
Private secondary school	15 (31.9: 19.5-47.3)	6 (54.5: 24.6-81.9)	2 (12.5: 2.2-39.6)
Road light	8 (17.0: 8.1-31.3)	1 (9.1: 0.5-42.9)	0 (0.0: 0.0-24.1)
Piped water supply	43 (91.5: 78.7-97.2)	6 (54.5: 24.6-81.9)	1 (6.3: 0.3-32.3)
Sewage pipe	7 (14.9: 6.9-28.9)	0 (0.0: 0.0-32.1)	0 (0.0: 0.0-24.1)
Garbage collection	24 (51.1: 36.3-65.7)	0 (0.0: 0.0-32.1)	0 (0.0: 0.0-24.1)
Provision of electricity	47 (100: 90.6-100)	9 (81.8:47.8-96.8)	4 (25.0:8.3-52.6)
Recent improvement of public facilities	22 (46.8: 32.4-61.8)	8 (72.7: 39.3-92.7)	3 (18.8: 5.0-46.3)

The proportion of LC1s having road light was not significantly different between urban and peri-urban LC1s (x^2=0.04, df=2, p=0.85). There was no rural LC1s having road light. The percentage of LC1s having piped water supply in urban areas (91.5%) was significantly larger than in peri-urban areas (54.5%, x^2=6.9, df=1, p=0.01), and the percentage was significantly higher in peri-urban areas than in rural areas (6.3%, x^2=5.6, df=1, p=0.02). The provision of sewage pipe and garbage collection service was seen only in urban LC1s. Electricity was supplied in all of urban LC1s. The percentage of LC1s with electricity supply was significantly higher in peri-urban areas (81.8%) than in rural areas (25.0%, x^2=8.4, df=1, p=0.004). The percentage of LC1s with recent improvement of public facility in peri-urban areas (72.7%) was significantly higher than in rural areas (18.8%, x^2=5.8, df=1, p=0.02), but was not significantly different from urban areas (46.8%, x^2=1.5, df=1, p=0.2).

Table 2.10 shows the details of the recent improvement of public facilities in the studied LC1s. Installation of piped water was the most common improvements and it was mainly seen in urban and peri-urban LC1s. Bore holes were still being installed in peri-urban and rural LC1s. Garbage collection service started only in urban LC1s (12.5%). Road light was being installed both in urban and peri-urban LC1s but not in rural LC1s.

Table. 2.10 The numbers of LC1s with recent improvement of public facilities (Percent, 95% CI)

	Urban	Peri-urban	Rural	Total
Number of LC1s	47	11	16	74
Piped water supply	16	5	1	22
	(34.0: 21.3-49.4)	(45.5: 18.1-75.4)	(6.3: 0.3-32.3)	(29.7: 19.9-41.6)
Bore hole	0	2	2	4
	(0.0: 0.0-9.4)	(18.2: 3.2-52.2)	(12.5: 2.2-39.6)	(5.4: 1.7-14.0)
Garbage collection	6	0	0	6
	(12.8: 5.3-26.4)	(0.0: 0.0-32.1)	(0.0: 0.0-24.1)	(8.1: 3.3-17.4)
Road light	5	1	0	6
	(10.6: 4.0-23.9)	(9.1: 0.5-42.9)	(0.0: 0.0-24.1)	(8.1: 3.3-17.4)

2.3.8. The relationships between the distance from city centroid and socio-economical factors

2.3.8.1. Transportation cost

The transportation cost increased over the distance from the city centroid but any obvious change was not observed around the peri-urban interface (12.1km, 95%CI: 10.5-13.9, Fig 2.15).
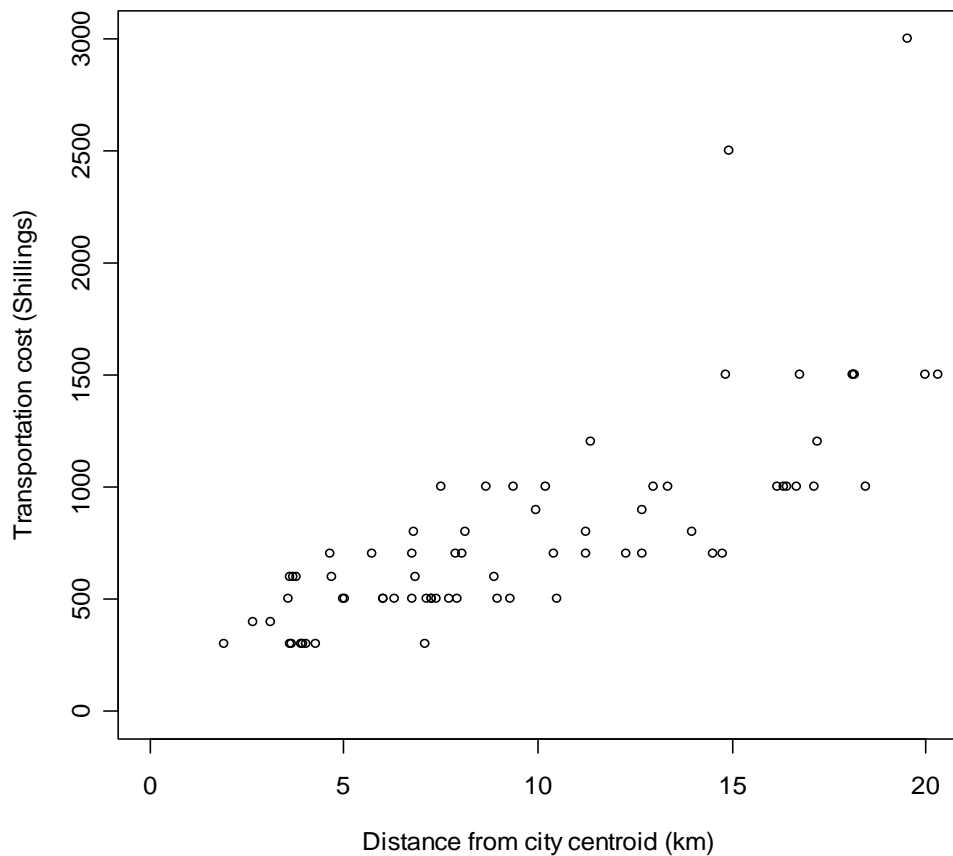
Fig. 2.15 The relationship between distance from city centroid (km) and transportation cost (Uganda Shillings). The transportation cost increased over the distance from the city centroid but any obvious change was not observed around the peri-urban interface (12.1km, 95%CI: 10.5-13.9).

2.3.8.2. Land price

The land price decreased over the distance from the city centroid but any obvious change was not observed around the peri-urban interface (12.1km, 95%CI: 10.5-13.9, Fig 2.16).
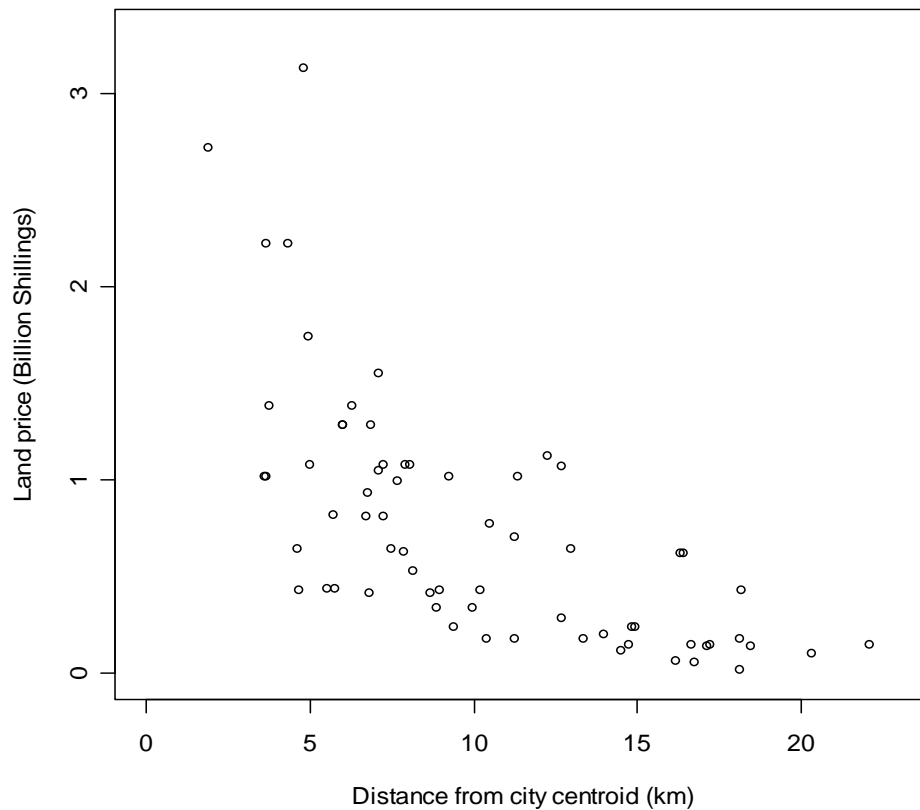
Fig. 2.16 The relationship between distance from city centroid and log of land price. The land price decreased over the distance from the city centroid but any obvious change was not observed around the peri-urban interface (12.1km, 95%CI: 10.5-13.9).

2.3.8.3. Public facilities

Fig 2.17 shows the relationships between the Euclidean distance from city centroid and the proportions of LC1s having public facilities. The factors were piped water supply, electricity, garbage collection service, recent improvement of public facilities, road light and sewage pipe. All lines shown are fitted lines by Generalised Linear Models with binomial errors. Fig 2.18 shows the fitted lines in separate graphs with their upper and lower 95% confidence interval lines.

The proportions of LC1s having piped water supply (slope=-3.1, p=0.01), electricity (slope=-5.8, p<0.001), garbage (slope=-2.6, p=0.03), road light (slope=-3.2, p=0.01) and sewage pipe (slope=-5.0, p=0.001) declined significantly with the increase of the distance from city centroid. The proportion of LC1s with recent improvement of public facilities showed a weaker relationship with the increase of the distance (slope=-2.0, p=0.08). Among these public facilities related to the distance from city centroid, piped water supply and electricity declined sharply around the peri-urban interface (12.1km, 95% CI :10.5-13.9, Table 2.7), especially piped water supply.
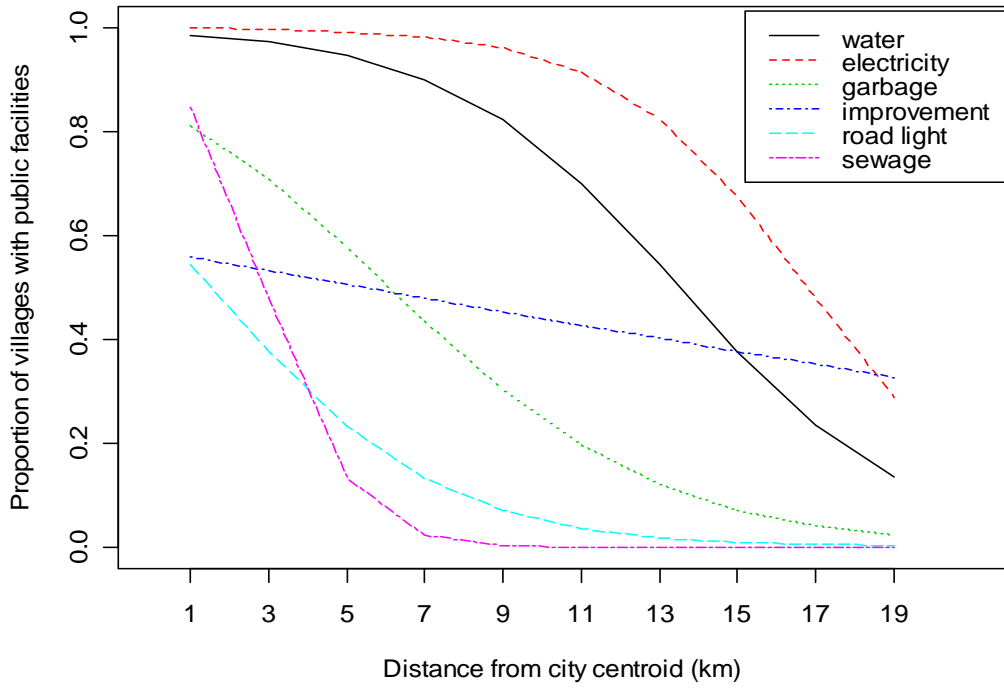
Fig. 2.17 Distance from city centroid and proportion of LC1s with public facilities
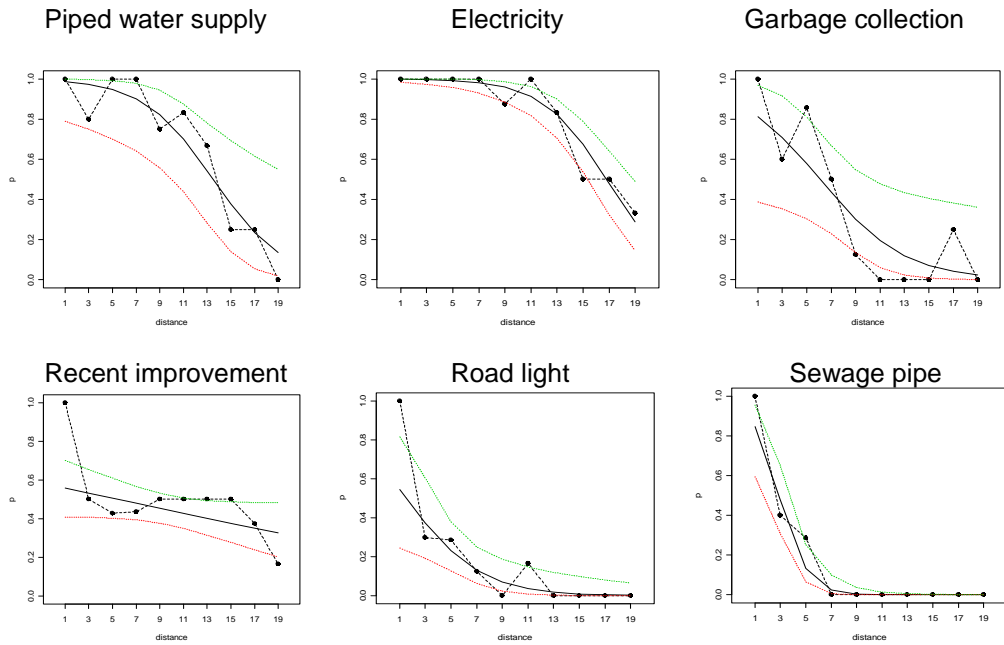
Fig. 2.18 Distance from city centroid and proportion of LC1s with each public facility (actual and fitted with 95% CI lines)

When only peri-urban LC1s were analysed, the proportions of LC1s with any of piped water supply (slope=-0.5, *p*=0.65), electricity (slope=-0.4, *p*=0.71), and road light (slope=-0.5, *p*=0.68) did not decline significantly with increase of the distance from city centroid (Fig 2.19, Fig 2.20). There was no garbage collection service and sewage pipe in the peri-urban LC1s.
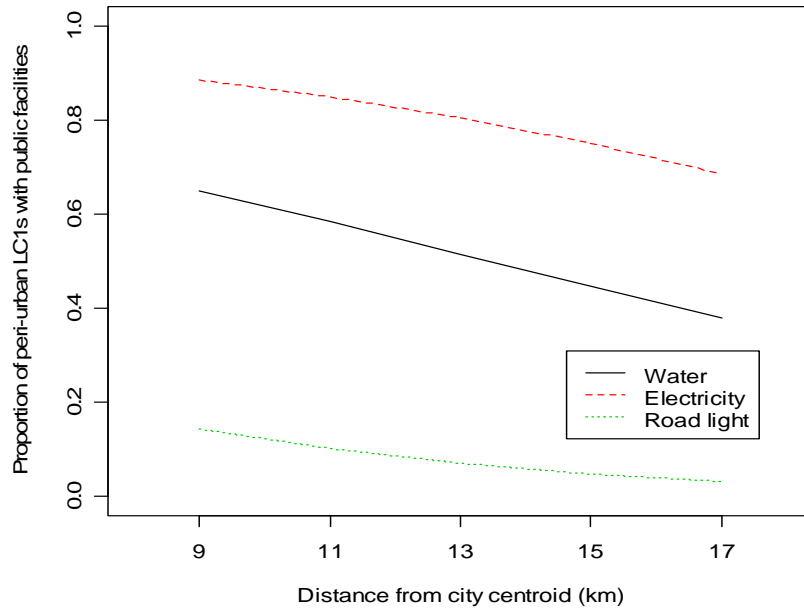
Fig. 2.19 Distance from city centroid and proportion of peri-urban LC1s with public facilities
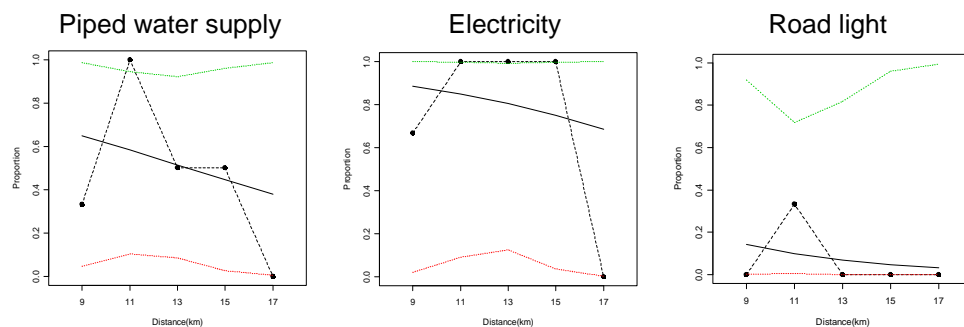
Fig. 2.20 Distance from city centroid and proportion of peri-urban LC1s with each public facility (actual and fitted with 95% CI lines)

2.4. Discussion

2.4.1. People's flow seen in urbanisation

According to FAO (2000), peri-urban areas receive up to 70 % of the migrants from rural areas as well as from the city itself. However, the people's flow found in the present study, regardless of the size of town, started from migration from rural to trading centres or slums, and city expanded with new house construction by city dwellers. In Upper Bavaria, Germany, migration of younger families from urban areas to peri-urban areas was reported. Rapid house construction was a feature of PUI in Greece and UK (NEWRUR 2004b). The predominance of younger families was also a feature in peri-urban rural areas in Quebec, Canada (Paquette & Domon 1999). These findings in Europe support the idea that the people's flow seen in urbanisation described by the present study may be universal. The discovery of a common rule in the flow of people seen in urbanisation enabled to develop the decision tree model of urbanicity classification and to determine the PUI in Kampala, Uganda. As this method is based on the common rule, it may be applicable to any size of village, town and cities, even smaller towns close to a larger city in any country. Testing this rule in the different cities in the other countries may prove its universality.

2.4.2. Contributions of the factors to determination of urbanicity level

The computed model and complexity analysis found the order of the degree of contributions of the factors to determination of urbanicity level. The percentage of full-time farmer contributed the most, and speed of population change and source of the population change followed it. Observational and agricultural data were not

measured with the same scale as above, however they were essential factors for the urbanicity classification of LC1s.

In the field, the interface between middle income residential areas and peri-urban areas was always difficult to judge even with the visual information. This is quite natural because the wave of peri-urbanisation always moves from the city outwards with a continuous vague gradation. Researchers should bear in mind that the observation on the ground may give a biased impression. Agricultural fields can be hidden behind the crowded settlements as peri-urban areas are heterogeneous. Aerial photography data can be the alternative tool of agricultural and observation data. However, direct visits and interviews regarding population change were still thought to be very important to the PUI unless fine demographic data is available.

2.4.3. Spatial distributions of urban, peri-urban and rural areas in Kampala and Kamuli

Spatial distributions of urban, peri-urban and rural LC1s in Kampala (Fig 2.12) and Kamuli (Fig 2.13) enabled us to understand the size and the shape of the city and the town. Initially the shape of the PUI in the Kampala economic zone was thought to be more skewed by the influence of Entebbe, former capital city under British colonial rule. However, Kampala was expanding in a concentric fashion. Understanding of the history helped to understand that Kampala was the origin of current city areas and it developed in a relatively short time without influence of other older cities. Even during the time when Entebbe was the administrative centre, Kampala remained as the economical centre. Compared to Kampala, the size of Kamuli town

was very small, but urbanisation and expansion of the small town were observed; new houses are being constructed in two peri-urban LC1s (0.8km and 1.7km from town centre). From the spatial distribution of urban LC1s in Kampala of which development types were classified, we could observe almost an intact trace of history in the development of Kampala City. Most of the slum areas and high income residential areas remained in the same locations and beyond the old structures, middle income residential areas, trading centres and peri-urban areas were expanding.

2.4.4. Socio-economic factors related to peri-urban interface

Socio-economic factors related to the PUI of the Kampala economic zone were determined. Peri-urban LC1s were characterised by the middle range of several variables: household density, Euclidean distance from city centroid, transportation cost to Kampala Taxi Park and percentage of full-time farming household. The finding on intermediate range of transportation was consistent with peri-urban areas in Kumasi, Ghana (Adam 2001).

The walking time to the nearest trading centre revealed that life in the peri-urban interface was as convenient as urban areas in terms of the access to commodity (p=0.488) and the time took significantly longer in rural areas (p=0.010). Pollution was perceived both in urban and peri-urban LC1s to a similar degree but not perceived in rural in the Kampala economic zone. The most popular complaint was plastic bags thrown away. In Habli-Dharwad, India, peri-urban villagers feared increased air and water pollution from growing city and loss of common land and

open space (Patil 1999), and peri-urban interface was the chosen location for the cities landfills, where waste pickers operate (Brook 2000). In fact one peri-urban LC1 leader appealed their fear of the pollution from nearby urban waste landfill in the Kampala economic zone in the present study; however, statistics did not show strong perception of pollution among people in peri-urban Kampala. In Kumasi, Ghana, environmental degradation was less recognised in peri-urban settlements than elsewhere as a recent negative change (Adam 2001). Perception of pollution may not be a particular indicator of peri-urbanicity.

Land price was tested for the similarity with the description by Cavailhes & Wavresky (2003) that farmland prices fall sharply close to the city and then gently further away in France. In Kampala, the results showed a similar finding that the mean land price in urban areas was significantly higher than peri-urban areas and rural land price did not differ from that of peri-urban areas. Land price decreased over the distance from city centroid but any obvious change of the price was not observed around the peri-urban interface. Land price was not an indicator of peri-urbanicity.

The proportions of LC1s having piped water supply, provision of electricity, garbage collection service, road light and sewage pipe significantly declined over the distance from city centre. Among them, the proportions of LC1s with piped water supply and electricity declined sharply around the PUI. Moreover, the proportions of peri-urban LC1s with piped water supply, provision of electricity and road light did not change over distance from city centroid. It was interpreted that peri-urban LC1s have common characteristics on piped water supply, provision of electricity and road light

regardless to the distance from city centroid. Road light should be excluded from peri-urban indicators as the proportion was too low. Therefore, the provision of electricity and piped water supply were good indicators of the PUI of Kampala. As the proportion of peri-urban LC1s with electricity was large, electricity may be provided just before peri-urbanisation starts. Piped water was supplied to around half of the peri-urban LC1s; it may be the best indicator of the PUI of Kampala. Interestingly, in Kumasi, Ghana, peri-urban settlement had recent improvements in health, electricity and public toilet facilities (Adam 2001). As he mentioned, electricity should be provided a few years before the wave of peri-urbanisation reaches. In the PUI of Hubli-Dharwad, India, electricity is extended to the more accessible villages, where provision is between 80 and 100%, and piped water is extended to some peri-urban villages (Hunshal 1997; Brook 2000). These findings can be similar in other cities in developing countries. To start with the survey, obtaining maps of electricity or piped water supply will be useful to estimate the spatial distribution of peri-urban areas, and there can be the other indicators such as the antennas for mobile phone. The details of recent improvement of public facilities supported the findings in the relationship between the proportion of LC1s with public facilities and the distance from city centroid. Piped water supply and installation of road light started in urban and peri-urban areas recently, but road light were being installed in lower percentages. Recent provision of electricity also should have been included in the questionnaire but was not in the present study.

There were some other sociological factors which were not consistent with the studies carried out by the other studies. For example in Kumasi, peri-urban settlements had more land disputes and junior secondary schools than the other

settlements (Adam 2001), but in Kampala, they did not. Each town or city may have its unique features.

This method used in the present study is handy, rapid and accurate and would be useful especially for resource poor countries. However, there is no doubt that fine airborne information would be very supportive. Also, this method is thought to be applicable for any field of studies, and to be able to contribute to the solution of the wide range of problems seen in urban and peri-urban areas in the developing countries.

3. Chapter 3 Urban and peri-urban agriculture in Kampala

3.1. Introduction

3.1.1. Aims

The aim of this Chapter is to understand the characteristics of agriculture in urban and peri-urban areas of Kampala, Uganda. Firstly, possible risks of zoonotic disease transmission in the areas will be discussed, since understanding the characteristics of livestock farming and marketing systems are key steps in analysing food borne zoonotic diseases. Secondly, the dependency of urban and peri-urban populations on agricultural activities for food security will be discussed. These two studies will be useful tools for policy makers to either restrict or even prohibit agricultural practices which present health risks, or to promote agriculture to meet food security needs. Among the many environmental health hazards presented by urban agriculture, this study concentrates on zoonotic risks posed by livestock farming and the unsafe handling of livestock products.

3.1.2. Characteristics of urban and peri-urban agriculture

The characteristics of urban and peri-urban agriculture have been described in detail in Chapter 1 (section 1.3), but are briefly listed here. "Urban" agriculture (UA) refers to small areas (e.g. vacant plots, gardens, verges, balconies, containers) within the city used for growing crops and raising small livestock or milk cows for owner-consumption or for sale in neighbourhood markets. "Peri-urban" agriculture (PA) refers to farm units close to town which operate intensive, semi- or fully commercial enterprises to grow vegetables and other horticulture, raise chickens and other livestock, and produce milk and eggs. However, the boundaries between urban, peri-urban and rural activities are ambiguous (FAO 2000) and urban and peri-urban agriculture now tend to be considered as a single research and development area

(Adam 2001), UPA, 'urban and peri-urban agriculture'. However, in this thesis, UA and PA will be characterised separately.

UPA is characterised by its significant opportunities and risks. Opportunities are the large demand for food in the city, low cost of transportation, freshness of the product due to less transportation time, employment, access to new technology and technical support (FAO 2000), enhancement of food security (Maxwell 1995; Ellis & Sumberg 1998; Sumberg 1999) and stability of food supply and price (Mougeot 2000). Risks are increased competition for resources (land, water, energy and labour) (Ellis & Sumberg 1998; Drechsel *et al.* 1999), nutrient mining (Stoorvogel & Smaling 1990) and environmental and health hazards such as use of untreated human and animal waste, re-use of urban waste and wastewater, heavy metal contamination in soils and irrigation waters, insect and arthropod vector breeding pools, pollution from chemical and industrial byproducts, hospital wastes and zoonoses (Flynn 1999).

3.1.3. Urban and peri-urban agriculture (UPA) in developing countries

UPA is common in developing countries; in cities and towns in East Africa, on average around a third of urban dwellers are engaged in agriculture (Lee-Smith 2006). In Kampala, 34.8% of the households in the city were found to be engaged in agriculture, with poultry farming particularly popular (Maxwell 1995). In Nairobi, livestock farming is seen in the outskirts of the city in predominantly small scale enterprises (Foeken 2000). As much as 90% of leafy vegetables and 60% of all milk sold in Dar es Salaam, Tanzania, is produced in and around the city (Lee-Smith 2006). This high level of urban and peri-urban milk production is also found in Addis Ababa, Ethiopia (Lee-Smith 2006).

In West Africa, the percentage of urban dwellers engaging in agriculture varies from more than 50% in Dakar, Senegal, to 14 % in Accra, Ghana (Lee-Smith 2006). The features of peri-urban agriculture in Kumasi, Ghana were the presence of commercial poultry farms and vegetable farming. Tree crop and intensified cereal crop productions in peri-urban areas were more popular than in the villages closer to the city but less popular than in the villages further away from the city. Conversely, backyard gardens were seen the most in the villages closer to the city, less so in peri-urban areas with few villages further away (Adam 2001). In Accra, Ghana, much of the farming in the city was on household property, but informal access to land, such as areas along power lines, was also important. The main livestock species kept for commercial purposes were poultry and pigs, and the farming activities took place on the outskirts of the city. Small ruminant and poultry farming was the largest farming category within the city (Armar-Klemesu 2000).

In northern Africa, Cairo, which is located in an arid landscape in Egypt, there is little space available which could function as green space, and there are almost no private gardens suitable for cultivation. Urban farming is thus chiefly restricted to small livestock production. In peri-urban districts, agricultural areas are irrigated by canals, and mainly clover is grown on the plots which yields high prices as fodder for livestock. Vegetable growing such as watercress, parsley, melon and lettuce is a serious health risk of heavy metal contamination in Greater Cairo that has an industrial district (unpublished study by El-Fouly 1991). Some 16% of Cairo households keep animals, predominantly chickens, geese, ducks and pigeons. Of the production, 95% was for home consumption, and poultry farming was almost

exclusively undertaken by low-income groups in densely-populated quarters of the city. Commercial poultry production takes place on rooftops of residential buildings, in small alleys and other available spaces, often inside houses. Raising and slaughtering of sheep is a very common seasonal activity in Cairo as part of religious practice. Commercial pig raising is a special type of urban livestock production undertaken only by Christian minority groups. Cattle rearing is found mainly in peri-urban districts (Gertel 2000).

In Habli-Dharwad, India, the dominant crops in the peri-urban interface (PUI) are cotton, onion, potato, green gram, groundnut, sorghum, wheat, safflower, chickpea and rice (Brook 2000; Khan 1997). Growing fruit and vegetables is not common in urban centres across India (Nunan 2000). Cattle and buffalo occupy a very special position in Indian cities because these animals are regarded as sacred in Hindu culture. However access to grazing is limited within the city and these free-ranging animals are fed vegetable waste or 'handouts' from those 'anxious to please the gods' (Brook 2000). Animals were rather more common in peri-urban areas than in the city, however urban farming was common and there were 10,000 to 16,000 animals in the city. Goats and sheep were reared in the outskirts of the cities and poultry farms were found to be well run (Brook 2000; Khan 1997). A significant number of scavenging pigs was seen in the city, but Hubli-Dharwad Municipal Corporation has been rounding up pigs and sending them out of the city, to a forest area around 10km away, in response to complaints about roaming pigs and potential health risks (Nunan 2000).

The highest levels of urban and peri-urban vegetable supply are seen in China; 76%

of total supply in Shanghai and 85% in Beijing. Intensive vegetable and fruit production is a widespread livelihood option for urban populations in Beijing: 31% of people engaged in urban areas, and 64% in peri-urban areas. However in Southeast Asia, UPA is a much smaller supplier of food or source of livelihoods. In Metro Manila for example, 6% of land is allocated for agriculture including 2% for fishponds (Lee-Smith 2006).

In Latin America, in the early 1990s, a food crisis in Cuba due to the collapse of the eastern European bloc and intensified US economic blockades led to a massive increase in urban agriculture (Bourque 2003; Lee-Smith 2006). In Lima, Peru, between 15 and 20% of households are engaged in UPA, mostly landless families raising poultry and other small animals (Lee-Smith 2006).

3.1.4. Previous studies on UPA in Kampala, Uganda

Urban Harvest (previously known as the Strategic Initiative on Urban and Peri-urban Agriculture (SIUPA) (a CGIAR system-wide initiative convened by the International Potato Centre (CIP) in 1999) operated in three African cities: Yaounde, Cameroon, Kampala, Uganda, and Nairobi, Kenya. The Uganda project "Strengthening urban and peri-urban agriculture in Kampala", coordinated by the International Centre for Tropical Agriculture (CIAT), sought to characterize and diagnose three aspects of urban farming systems: livelihoods, production systems and market opportunities. Another project funded by Canadian CIDA - "Health Impact Assessment of UA in Kampala", is linked with Urban Harvest (King'ori 2004). In Uganda, many studies on UPA have been done but remain unpublished. As a part of the Urban Harvest project, an annotated bibliography of previous UPA studies in Kampala has been

published (Kimeze 2005).

In 1994, 50% of the land in Kampala was farmed by about 30% of the total population and 70% of the poultry and eggs consumed in the city were produced in the city (Egziabher 1994). Maxwell *et al*. (1995) reported 34.8% of the households in the city engaged in agriculture (9.5% kept livestock and 33.9% cultivated crops). Maxwell *et al*. (1995) showed that UPA was practiced by all wealth groups. An estimated 83% of urban farming households were found to be involved in backyard farming on less than one acre of land, 10% of urban farmers cultivate between 1 and 3 acres, 5% farmed on more than 3 acres in peri-urban areas, and institutions and schools make up the remaining 2% (Kimeze 2005; Ssemwanga 2002). The most common food crops grown in and around Kampala were cassava, sweet potatoes, beans, maize, cooking bananas (matoke), cocoyam (taro), vegetables, sugar cane, ground nuts and coffee. With regard to livestock, the number of indigenous cattle in Kampala District has decreased due to the restriction of free-range cattle keeping by city authorities, and the number of exotic and cross breeds under zero-grazing systems has increased (Development Consultants International Ltd. 1997; Kimeze 2005). A study of 4 parishes categorised as (i) urban, old (Bukesa parish), (ii) urban, new (Banda), (iii) peri-urban to urban transition (Buziga), and (iv) peri-urban (Komanboga) compared characteristics of agriculture in Kampala. In less urbanised areas (peri-urban to urban transition and peri-urban), the purpose of farming for the majority was to meet food security. Relatively few farmers were involved in income generating activities in these areas. By contrast, the agriculture in more urbanised areas was market oriented. The products for food security were bananas, indigenous vegetables and cocoyam in urban areas, and sweet potato and cassava in peri-urban

areas. The main activities for income generation were poultry and dairy in urban and peri-urban in urban transition, and pigs and dairy in peri-urban areas (Atukunda 2003; Kimeze 2005). However, this study may have been biased as only one parish was studied in each level of urbanicity.

Urban agriculture has been shown to have a positive impact on food security and nutrition status of households, especially among children as measured by height for age in Kampala (Maxwell 1999). A study in wetlands of Kampala showed women depend more on agriculture and this supplementary income reduces women's dependence on their husbands and increases their decision making power within their households (Nakijoba 1996). Kampala farmers also have easier access to extension services compared with their rural counterparts (Development Consultants International Ltd. 1997). However, health hazards are a major challenge for UPA in Kampala. Wastewater released by some Ugandan industries into agricultural land contains heavy metals with higher concentrations than internationally accepted levels, and vegetables sampled from these industrial areas were found to have higher concentrations of zinc, lead and copper than those grown at sites irrigated by municipal wastewater and solid waste from dumping sites (Nabulo 2003). Studies of animal-to-human disease transmission found that brucellosis was widespread in livestock in both urban and peri-urban areas of Kampala (Lee-Smith 2006). Urban agriculture can pose the other environmental health concerns e.g. poor methods of waste disposal resulted in an increase in the prevalence of disease vectors such as vermin and malaria-carrying mosquitoes. Households living in or near farming areas in Kampala experienced more malaria and dysentery than those living away from farming areas mainly due to lack of proper sanitation facilities (Nuwagaba 2002).

Within Kampala, legislation inherited from the colonial period in theory still prohibits urban agriculture or sets limits on the types of crops grown with zoning rules being applied (Ssemwanga 2002). However, in practice, some farmers are not even aware that they lack the legal authority to practice urban agriculture (Musimenta 1997). Landlords and city authorities can evict illegal farmers at anytime if the occupied land is going to be developed. The Electricity Board often slashes crops where electricity lines run. This complex web of land management regimes results in constraints of access and ownership. The colonial British administrators introduced a land tenure system in 1900, under which land was divided into mailo (from the English word mile) as private land belonging to the Ganda King and chiefs, and public land owned by the Queen of England. The majority of urban poor gain access to the land in peri-urban areas in a form of land tenure unique to the Buganda Kingdom known as *bibanja* on mailoland (Kiguli 2003).

Many studies have recognized the importance of urban agriculture in Kampala and usually recommended such activities be permitted in suitable locations, with appropriate policy support to ensure environmental sustainability (Davidson 1994; Kimeze 2005; Musimenta 1997; Nostrand van 1994; Nuwagaba 2002).

3.1.5. Crop production in Uganda

Box 3.1 shows the percentages of the top 10 most commonly grown crops among agricultural households during the first season of 2002 in Uganda (Uganda Bureau of Statistics 2002). Beans (39.2%) and cassava (38.2%) were grown by the highest percentages of households.

Box 3.1. Percentages of crop producing households among total agricultural households during first season of 2002 in Uganda (Top 10 most grown products) (Uganda Bureau of Statistics 2002)

Crop type	Percentage (%)
Beans	39.2
Cassava	38.2
Maize	30.0
Sweet potatoes	27.7
Banana	24.4
Groundnuts	14.9
Millet	14.8
Sorghum	12.6
Coffee	6.3
Simsim (sesame seeds)	4.0

3.1.6. Livestock farming in Uganda

Livestock species are listed in a report on Ugandan agriculture (Uganda Bureau of Statistics 2002) and are: exotic/ cross breed cattle, indigenous breed cattle, pigs, goats, sheep, exotic/ cross breed chicken, local chicken, ducks, turkeys, geese, guinea fowls, and fishes; percentages of households having these livestock species in Uganda are shown in Table 3.1 (data were extracted from Uganda Bureau of Statistics 2002). Exotic/cross and indigenous breed cattle, pigs, goats, sheep and exotic/cross and local chicken were found to be most popular in Uganda.

Table. 3.1 Percentages of households rearing livestock among total agricultural households (3,833,485), and number of animals or birds or ponds in Uganda (Uganda Bureau of Statistics 2002)

Livestock species	Households	Percentage(%)	Number of animals, birds, ponds
Exotic/cross breed cattle	77,009	2.0	533,095
Indigenous breed cattle	752,195	19.6	5,749,412
Pigs	370,905	9.7	773,386
Goats	1,165,889	30.4	5,168,023
Sheep	233,750	6.1	1,555,431
Exotic/cross breed chicken	Not shown	0.7	1,828,638
Local chicken	Not shown	46.4	11,030,699
Ducks	Not shown	Not shown	685,334
Turkeys	Not shown	Not shown	195,032
Geese	Not shown	Not shown	16,978
Guinea fowls	Not shown	Not shown	66,209
Fish ponds	7,152	0.19	29,999

3.2. Materials and methods

3.2.1. Study site

The study sites selected were 75 LC1s (Local Council I) in and around Kampala, the capital city of Uganda (Fig 3.1). LC system of Uganda was described in Chapter 2, Section 2.1.3.
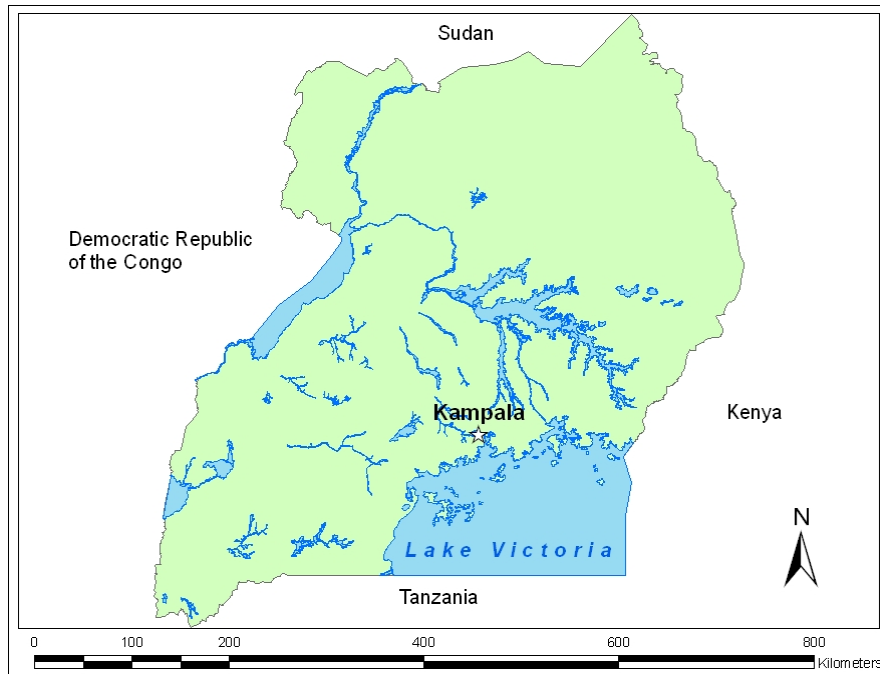
Fig. 3.1 Map of Uganda showing the location of Kampala City

Eighty seven LC1s were randomly selected from the 790 LC1s in the 10 LC3s (highlighted in Fig 3.2). Twelve LC1s were excluded: 7 urban LC1s were institution/ university, 4 urban LC1s were located in very high income residential areas, and 1 rural LC1 was a prison. A total of 75 LC1s were included in this study (Fig 3.2). The details of the selection procedure are described in Chapter 2 (Section 2.2.2). The 10 LC3s selected were Kawempe and Nakawa Division in Kampala District, Kira, Makindye, Nabweru, Nangabo, Nsangi, Ssisa, Wakiso Sub-Counties in Wakiso

District, and Goma Sub-County in Mukono District.
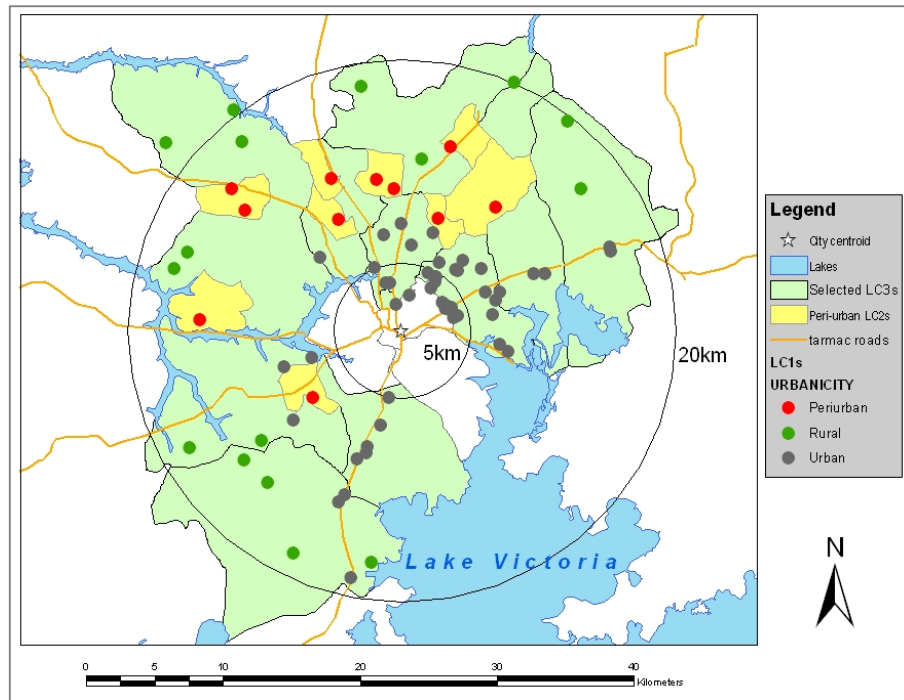
Fig. 3.2 Map showing selected LC3s (highlighted) and the subsequently selected 75 LC1s with their levels of urbanicity

The 75 LC1s selected were classified into 48 urban, 11 peri-urban and 16 rural LC1s (Fig 3.2), and their development types were determined by the author (Fig 3.3, Table 3.2). The definitions of levels of urbanicity and development types of LC1s were described in Chapter 2, Section 2.2.8.

Table. 3.2 Urbanicity and development type of the LC1s

Development type	Urban	Peri-urban	Rural
City centre	1		
High income residential area	2		
Middle income residential area	22		
Slum	6		
Trading centre	17	2	1
Peri-urban		9	
Rural			15
Total	48	11	16
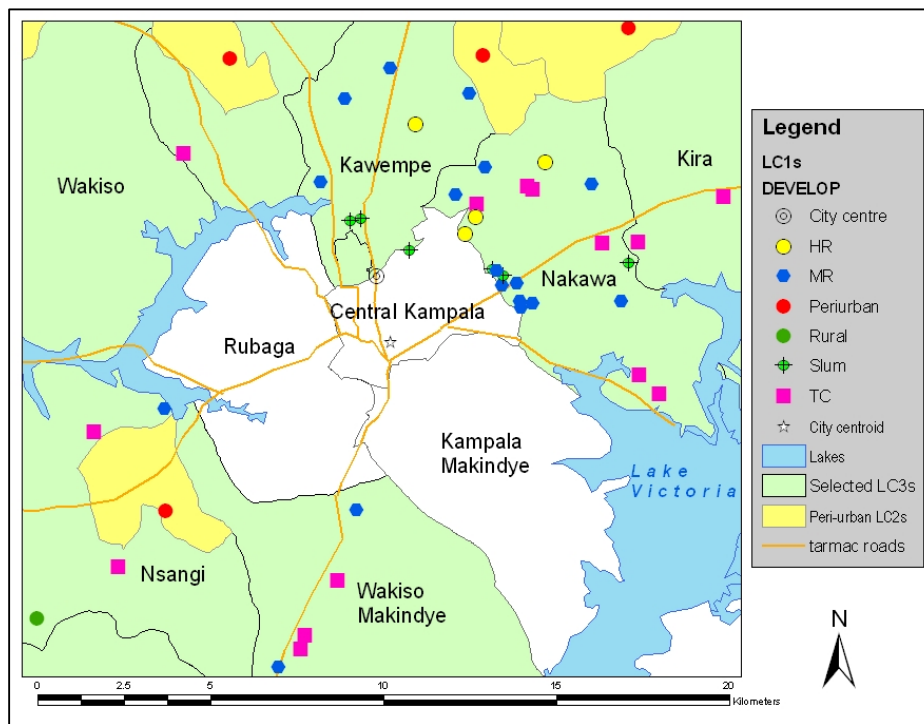
Fig. 3.3 Map of studied urban LC1s and their development types

3.2.2. Collection of information

Information relating to crop production and livestock farming was collected during the Village Characteristic Survey (VCS, refer to Section 2.2.4). The details of the questionnaire are shown in Box 3.2 (shown full in Appendix I). The crops and livestock species were selected by the author during a prior visit to Kampala by observing the popular foodstuffs seen at local restaurants. Selected crop products were plantain (banana locally called *matoke*), maize, rice, tomato and green leafy vegetables. Plantain is boiled, mashed and steamed to prepare *matoke*, which is a staple food in Uganda. Uganda is, per capita, one of the world's largest banana producers and consumers (Harper 2004). Maize flour is boiled to prepare posho which is also a popular staple food in Uganda. Livestock species were selected in the same manner; beef, goat meat, and chicken were the most common meats cooked in restaurants and were served with soup. Pork was a popular food served in pubs. Sheep were also selected although their meat was never seen in local restaurants. Selected livestock species observed were improved and cross breed cattle, indigenous breed cattle, pig, goat, sheep, broiler, layer and indigenous chicken.

Tomato and green leafy vegetables were selected to examine whether they can serve as indicators of peri-urban agriculture in Kampala. A study in West Africa showed that peri-urban market producers were characterised by the production of vegetables of higher value (tomatoes, onions, cabbages, eggplants and peppers) and perishable leafy vegetables (Drechsel 2004). It has also been shown in Kumasi, Ghana that farmers in peri-urban areas specifically sell tomatoes in the city market (Adam 2001).

Box 3.2 Contents of the questionnaire regarding agriculture

1. Crop farming

·Number of households growing banana, maize, rice, tomato and green leafy vegetables

·Number and names of large scale growers

2. Livestock farming

·Number of households keeping improved and cross breed dairy cattle, indigenous cattle, pigs, goats, sheep, broiler, layer, and indigenous chicken

·Number, names of large scale livestock farmers, and their herd size

·Average number of animals (birds) kept in a small scale farm

·Number of households selling livestock or their products to markets in Kampala

Markets in Kampala used in the questionnaire are defined as large scale markets dealing in food. There are three large markets in Kampala: Nakasero, Nakawa, and Owino markets.

3.2.3. Definition of large scale farms

Box 3.3 defines large scale crop and livestock farms. 'Large scale farm' was defined as a farm which operates in large scale for at least one sector; for example, a large scale plantain farm with a cow is classified as a large scale farm. Statistics in Uganda used the definitions shown as UBOS (Uganda Bureau of Statistics) in Box 3.3 (UBOS 2003). However, for the present study, large scale farms were defined in much smaller sizes. In urban and peri-urban settings, because of the competition of lands, farm size must be smaller than rural settings. Moreover, in order to obtain a sufficient frequency of farms of different size, the cut-off size needed to be smaller, as estimates of farm size were only asked of participants with large scale farms, but average farm size was only asked for small scale farms participants (Section 3.2.2).

Box 3.3 Definitions of large scale farm		
Sector	**Uganda Bureau of Statistics**	**This study**
1. Plantain, maize, rice, tomato and vegetable farm	>=50 acres of cropland	>=10 acres of cropland
2. Improved and cross breed dairy farm	>=50 cows/ 200 L/day, farm	>=10 cows
3. Indigenous breed cattle farm	>=500 cattle	>=50 cattle
4. Pig farm	>=50 pigs	>=50 pigs/ 10 sows
5. Goat farm	>=100 goats	>=30 goats
6. Sheep farm	>=100 sheep	>=20 sheep
7. Broiler farm	>=5000 broilers	>=500 broilers
8. Layer farm	>=1000 layers	>=500 layers

3.2.4. Definitions of urban and peri-urban abattoirs

Urban abattoirs were defined as those located in the areas within an 8.7 km radius from the city centroid of Kampala; the 95% confidence interval of the mean distance from the city centroid to urban areas was 4.7 and 8.7 km (Table 2.7, Chapter 2). Peri-urban abattoirs were defined as those located in areas outside an 8.7 km radius from city centroid.

3.2.5. Geographical data

The locations of LC1s, city centroid and abattoirs were recorded with a hand-held Global Positioning System (GPS, Garmin, Olathe, KS, USA). All GPS readings were taken at the LC1 office or the village leader's residence where interviews were performed. The location of city centroid was taken in Nakasero. These locations were transferred from the GPS to MapSource (Garmin, Olathe, KS, USA), and converted into DBF4 file using Microsoft Excel (Microsoft Office XP, Redmond, USA). Geographical data of LC3 boundaries, and other shape files were obtained from Land and Surveys Department, Ministry of Land Housing and Urban Development of Uganda. Euclidean (straight line) distance between the city centroid and each abattoir was calculated using ArcView version 3.1 (ESRI Systems, Redlands, CA, USA). The National Biomass Study, from which the spatial data layers were obtained, is provided by the Universal Transverse Mercator (UTM) projection, with detailed parameters as shown in Box 2.2 in Chapter 2, Section 2.2.5. GPS data were collected in latitude/longitude format, in the WGS 84 datum, and were converted to the Biomass projection for processing of maps using ArcView 3.1. Maps were produced using ArcGIS 9 (ESRI Systems, Redlands, CA, USA).

3.2.6. Statistical analysis

All of the data analysed in this chapter were collected from interviews in 75 LC1s during the VCS. The data was analysed to compare the characteristics of agriculture among urban, peri-urban and rural areas. The sample fraction of LC1s in this study was 11.0% of the total LC1s in 10 selected LC3s (87/ 790 LC1s, described in Chapter 2, and section 3.2.1 of this Chapter). As the LC1s were randomly selected, the number of households and animals (birds) in the 10 selected LC3s (Kawempe and Nakawa Division in Kampala District, Kira, Makindye, Nabweru, Nangabo, Nsangi, Ssisa, Wakiso Sub-Counties in Wakiso District, and Goma Sub-County in Mukono District) may be estimated multiplying the numbers in the 75 LC1s by the reciprocal of sampling fraction (9.08, 790/ 87 LC1s).

3.2.6.1. Comparison of urban, peri-urban and rural crop production

Proportion of LC1s having crop producing households

The proportions of LC1s with crop producing households were compared among urban, peri-urban and rural areas using a GLM (Generalised Linear Model) with binomial errors in statistics software R 2.4.1 (Crawley 2002). As all of peri-urban and rural LC1s produced plantain, they were combined and compared with urban LC1s. For the other crops, when there was a significant difference among three groups (at least one group was significantly different), each of two groups (urban and peri-urban, peri-urban and rural, rural and urban LC1s) were compared. The 95% confidence intervals of the proportions of LC1s with crop-producing households, presented in tables, were calculated using one-proportion Chi-square test in R 2.4.1.

Proportion of households engaged in crop production

The overall percentages of households engaging in each type of crop production in urban, peri-urban, and rural LC1s were calculated, and their 95% confidence intervals were also calculated using a one-proportion Chi-square test in R 2.4.1. Then, the proportion of households engaged in crop production in each LC1 was compared among urban, peri-urban and rural LC1s using a GLM with binomial errors in statistic software R 2.4.1. The box and whisker plots of the data were produced using R 2.4.1, and lines of median, 25th and 75th percentiles, and 1.5 times interquartile range (Crawley 2002) were presented.

Ranking popularity of crop production

The rank in popularity of crop productions was determined by comparing the proportions of households producing the selected crops in all of 75 LC1s. Firstly, the proportions for all crops were compared, then secondarily, each two neighbouring ranks were compared using a Chi-square test in R.2.4.1.

Sales destinations of crops

Sales destinations of the crops in urban, peri-urban and rural LC1s were analysed using Chi-square test in R.2.4.1. When there was a significant difference among three urbanicity groups (means at least one group is significantly different) in Chi-square test, each adjacent two groups (urban and peri-urban, peri-urban and rural) was compared in Chi-square test. When more than one expected frequency was less than 5 in a Chi-square test, Fishers' Exact Test was used in R 2.4.1 (Crawley 2002).

3.2.6.2. Comparison of urban, peri-urban and rural livestock farming

Proportions of LC1s with each livestock species

The proportions of LC1s with each livestock species were compared among urban, peri-urban and rural LC1s using a Generalised Linear Model (GLM) with binomial errors in statistical software R 2.4.1. As all of peri-urban and rural LC1s had improved and cross breed cattle, any breed of cattle, pig, goat and indigenous chicken, peri-urban and rural LC1s were classified into one group 'peri-urban-rural', to compare with the urban LC1s. For the other livestock species: indigenous breed cattle, sheep, broilers and layers, when there was a significant difference among three groups, each of two groups (urban and peri-urban, peri-urban and rural, rural and urban LC1s) were compared using a GLM with binomial errors. A GLM with quasibinomial errors was used when the ratio of the residual deviance and degree of freedom was larger than one- defined as 'over-dispersion' (Crawley 2002). To present the percentages in tables, 95% confidence intervals were calculated using one-proportion Chi-square test in R 2.4.1.

Proportion of households keeping each livestock species

The overall percentages of households keeping each livestock species in urban, peri-urban, and rural LC1s were calculated, and their 95% confidence intervals were also calculated using one-proportion Chi-square test in R 2.4.1. Then, the proportion of households keeping each livestock species in a LC1 was compared among urban, peri-urban and rural LC1s using a GLM with binomial errors in statistic software R 2.4.1. The box and whisker plots of the data were produced using R 2.4.1, and lines of median, 25th and 75th percentiles, and 1.5 times interquartile range (Crawley 2002) were presented.

Ranking popularity of livestock species

The rank in popularity of livestock species was determined by comparing the proportions of households keeping the selected livestock species in all the 75 studied LC1s. Firstly, the proportions of households keeping livestock among all the selected livestock species were tested for significant difference, then secondarily, each two neighbouring ranks of livestock species were tested using Chi-square test in R.2.4.1.

Farm (herd) size

The relationships between number of herds (farms) and herd (farm) size were compared among urban, peri-urban and rural LC1s using ANCOVA in a GLM with Poisson errors in statistic software R 2.4.1, to investigate the intensity of livestock farming in different levels of urbanicity. A GLM with quasipoisson errors was used when the ratio of the residual deviance and degree of freedom was larger than one (over-dispersion) (Crawley 2002). The lines of predicted values by the log-linear model were drawn in graphs in the original scale using 'response' function in R 2.4.1(Crawley 2002). The geometric mean (Crawley 2002) was used to calculate the mean herd (farm) size using R 2.4.1 because there were some very big outliers and that the error structures were not normally distributed. The commands for geometric mean calculation in R 2.4.1. are shown in Box 3.4.

Box 3.4 R-commands for geometric mean

```
> data<-rep(Size,Herds)
> geometric<-function(x)exp(sum(log(x))/length(x))
> geometric(data)
```

Proportion of large scale livestock farms

The proportion of large scale livestock farms was also compared among urban, peri-urban and rural LC1s using Chi-square test in R 2.4.1 to determine the relative intensity of livestock farming. When there was a significant difference among the three levels of urbanicity, each two groups (urban and peri-urban, and peri-urban and rural LC1s) were compared using Chi-square test. However, when more than one expected frequencies was less than 5 in a Chi-squared test, Fisher's Exact Test was used in R 2.4.1(Crawley 2002).

Animal (bird) density against human density

The purpose of this study is to determine the risks of zoonoses in urban and peri-urban populations in the Kampala economic zone. Therefore, the number of animals per thousand households (i.e. the animal density compared with human density), was analysed to estimate the risks of zoonotic infection. In all livestock species, the numbers of animals per thousand households in three urbanicity groups could not be compared straightforwardly in a one-way ANOVA, because there were many urban LC1s without certain livestock species (improve and cross breed cattle, any breed of cattle, pig, goats and indigenous chicken). The data in peri-urban and rural LC1s had to be transformed due to the skewed error structures, but data in urban LC1s that included zero could not be transformed. In these cases, firstly urban LC1s were simply judged to have fewer animals (birds) per households than peri-urban and rural LC1s, when the proportions of LC1s with the livestock species were less in urban areas than peri-urban and rural, and herd size was not significantly different among the three urbanicity groups. Secondarily, the numbers of animals per

thousand households in peri-urban and rural LC1s were transformed to either log or power. Box-Cox transformations were used to estimate the transformation parameter λ (lambda) in R 2.4.1 (**library (MASS)**, then **boxcox (y~x)**) (Box 1964; Crawley 2002). When $\lambda=0$, the data was log-transformed, and when $0<\lambda<1$, the data was powered by λ. Transformed data were compared between peri-urban and rural LC1s using a one-way ANOVA in R 2.4.1.

For indigenous breed cattle, sheep, broilers and layers, LC1s in more than two urbanicity groups did not have animals or birds, and again the error structures were not normally distributed. In these cases, the numbers of animals per thousand households were compared visually from Box and Whisker plots among urban, peri-urban and rural LC1s.

Sales destinations

Sales destinations of livestock and their products in urban, peri-urban and rural areas were analysed using Chi-square test in R.2.4.1. When there was a significant difference among three urbanicity groups (means at least one group is significantly different) in Chi-square test, each adjacent two groups (urban and peri-urban, peri-urban and rural) was compared with a Chi-square test. When more than one expected frequency was less than 5, Fishers' Exact Test was used in R 2.4.1 (Crawley 2002).

3.2.6.3. Urban crop production and livestock farming

To examine the dependence of city dwellers on urban agriculture and to estimate the impact of rigorous prohibition of urban agriculture, especially in slum areas, crop production and livestock farming in urban areas were compared among different development types (high income and middle income residential areas, slum, trading centre and city centre).

Chi-square tests were used for the analysis in R 2.4.1. When more than one expected frequency was less than 5 in a Chi-square test, Fishers' Exact Test was used in R 2.4.1(Crawley 2002).

3.3. Results

3.3.1. Comparison of urban, peri-urban and rural crop production

3.3.1.1.   Proportions of LC1s with crop producing households

Table 3.3 shows the proportions of LC1s with crop producing households. Plantain and maize were the most popular agricultural products.

The proportion of LC1s with plantain producers in urban areas (mean=0.52) was significantly lower than peri-urban and rural areas (mean=1.0, $p<0.001$).

The proportion of LC1s with maize producers in peri-urban areas (mean=1.00) was significantly higher than in urban areas (mean=0.44, $p<0.001$), but was not significantly different from rural areas (mean=0.94, $p=0.300$).

The proportion of LC1s with rice producers in peri-urban areas (mean=0.09) was not significantly different from rural areas (mean=0.13, $p=0.780$) or from urban areas (mean=0.0, $p=0.064$).

The proportion of LC1s with tomato producers in peri-urban areas (mean=0.64) was significantly higher than in urban areas (mean=0.21, $p=0.007$), and was lower than in rural areas (mean=0.94, $p=0.046$).

The proportion of LC1s with vegetable growers in peri-urban areas (mean=0.64) was significantly lower than in rural areas (mean=1.00, $p=0.003$), but was not significantly different from in urban areas (mean=0.31, $p=0.103$).

Table. 3.3 LC1s having crop producing households

	Urban	Peri-urban	Rural
Total number of LC1s	48	11	16
Plantain	25	11	16
Percentage (95% CI)	52.1 (37.2-66.7)	100 (76.2-100)	100 (82.9-100)
Maize	21	11	15
Percentage (95% CI)	43.8 (29.5-58.8)	100 (76.2-100)	93.8 (69.8-99.8)
Rice	0	1	2
Percentage (95% CI)	0.0 (0.0-6.1)	9.1 (0.2-41.3)	12.5 (1.6-38.3)
Tomato	10	7	15
Percentage (95% CI)	20.8 (10.5-35.0)	63.6 (30.8-89.1)	93.8 (69.8-99.8)
Vegetable	15	7	16
Percentage (95% CI)	31.3 (18.7-46.3)	63.6 (30.8-89.1)	100 (82.9-100)

3.3.1.2. Proportions of households engaging in crop productions

Table 3.4 shows a summary of households engaging in crop production in 75 LC1s. In Table 3.4, the numbers of households in the LC1s falling into each level of urbanicity were added up. Fig 3.4 compares the proportions of households engaging in crop production among the three urbanicity groups with the variances among LC1s weighed.

The proportion of households producing plantain in peri-urban LC1s (mean=0.62) was significantly higher than in urban LC1s (mean=0.07, $p<0.01$), but not significantly different from rural LC1s (mean=0.49, p=0.42, Fig 3.4 (A)).

Table. 3.4 Summary of households engaging in crop productions

	Urban	Peri-urban	Rural
Number of households	36,184	5,294	3,484
Plantain growers	2,588	3,318	1,696
Percentage (95% CI)	7.2 (6.9-7.4)	62.7 (61.4-64.0)	48.7 (47.0-50.4)
Maize growers	1,272	2,424	2,012
Percentage (95% CI)	3.5 (3.3-3.7)	45.8 (44.4-47.1)	57.7 (56.1-59.4)
Rice growers	0	3	14
Percentage (95% CI)	0.0 (0.0-0.0)	0.1 (0.0-0.17)	0.4 (0.2-0.7)
Tomato growers	91	262	1,011
Percentage (95% CI)	0.3 (0.2-0.3)	4.9 (4.4-5.6)	29.0 (27.5-30.6)
Vegetable growers	824	386	1,402
Percentage (95% CI)	2.3 (2.1-2.4)	7.3 (6.6-8.0)	40.2 (38.6-41.9)

The proportion of households producing maize in peri-urban LC1s (mean=0.46) was significantly higher than in urban LC1s (mean=0.04, $p<0.001$), but not significantly different from rural LC1s (mean=0.58, $p=0.50$, Fig 3.4 (B)). Rice growing activity was not popular in any of the urbanicity groups. The proportion of households producing tomatoes in peri-urban LC1s (mean=0.05) was significantly higher than in urban LC1s (mean=0.003, $p=0.011$) and significantly lower than in rural LC1s (mean=0.29, $p=0.004$, Fig 3.4 (D)). The proportion of households producing green leafy vegetables in peri-urban LC1s (mean = 0.08) was significantly lower than in rural LC1s (mean=0.40, $p=0.041$), but not significantly different from in urban LC1s (mean=0.02, $p=0.18$, Fig 3.4 (E)).
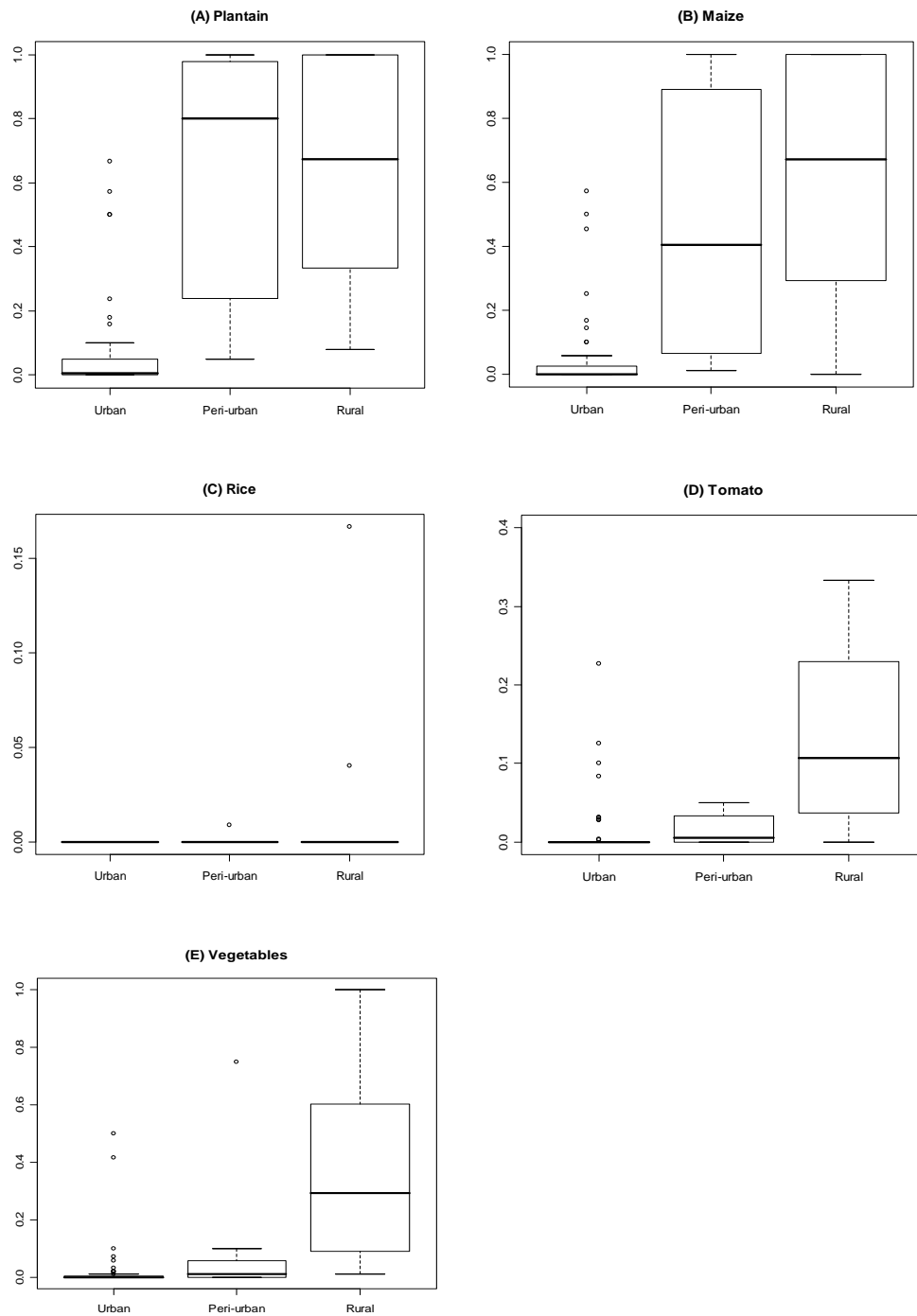
Fig. 3.4 Box and whisker plots showing proportions of households engaging in crop production in urban, peri-urban and rural areas of the Kampala economic zone; horizontal lines shown are median, 25th and 75th percentiles, and 1.5 times interquartile range.

3.3.1.3. Ranking popularity of crop production

When the proportions of households engaging in crop production were compared by product; plantain was the most popular product, and maize, vegetable and tomato followed with rice the least popular product in Kampala (Table 3.5). The proportions were significantly different among five products (x^2=12,129.3, df=4, p<0.001), and all of the proportions of neighbouring ranks were significantly different; plantain and maize (x^2=294.3, df=1, p<0.001), maize and vegetable (x^2=1,268.7, df=1, p<0.001), vegetable and tomato (x^2=409.2, df=1, p<0.001), and tomato and rice (x^2=1,332.3, df=1, p<0.001).

Table. 3.5 Ranks of popularity in agricultural products

	Kampala (44,962)		
	Households	Percentage	Rank
Plantain	7,532	16.8	1
Maize	5,708	12.7	2
Vegetable	2,612	5.8	3
Tomato	1,364	3.0	4
Rice	17	0.04	5

3.3.1.4. Sales destinations

Sales of plantain were found to be very rare and the purpose of production was mainly for home consumption in the Kampala economic zone. No plantain producers in urban and peri-urban areas, and only 44 of them (2.6%) in rural areas were selling

to a nearby trading centre. Only three producers in peri-urban areas and three in rural areas were selling plantain to markets in Kampala. Additional demand for plantain in Kampala appeared to be met from outside the Kampala economic zone (Table 3.6).

The proportion of maize growing households selling to a nearby trading centre in peri-urban areas (0.8%) was significantly higher than in urban areas (0.2%, x^2=5.2, df=1, p=0.022), and was significantly lower than in rural areas (6.0%, x^2=93.3, df=1, p<0.001). The proportions of maize growing households selling to markets in Kampala in peri-urban areas (0.2%) was significantly lower than in rural areas (2.3%, x^2=40.4, df=1, p<0.001), but was not significantly different from urban areas (0.3%, odds ratio=1.53, 95%CI: 0.30-7.10, p=0.50).

There was no rice grower selling rice to trading centres or markets in the Kampala economic zone. In informal interviews during VCS, LC1 leaders who had rice growers in their LC1s said this was because growers had just started rice farming.

Table. 3.6 Sales destinations of the crops produced in the Kampala economic zone

	Plantain			Maize			Tomato			Green leafy vegetable		
	Urban	P-U	Rural	Urban	P-U	Rural	Urban	P-U	Rural	Urban	P-U	Rural
Growers	2,588	3,318	1,696	1,272	2,424	2,012	91	262	1,011	824	386	1,402
Nearby TC*	0	0	44	2	20	120	2	13	150	1	43	97
Percentage	0.0	0.0	2.6	0.2	0.8	6.0	2.1	5.0	14.8	0.1	30.3	6.9
95% CI	0.0,0.1	0.0,0.1	1.9,3.5	0.0,0.6	0.5,1.3	5.0,7.1	0.3,7.7	2.7,8.3	12.7,17.2	0.0,0.7	25.8,35.2	5.6,8.4
Markets*	0	3	3	4	5	46	23	46	192	50	35	143
Percentage	0.0	0.1	0.2	0.3	0.2	2.3	25.3	17.6	19.0	6.1	40.2	10.2
95% CI	0.0,0.1	0.0,0.3	0.0,0.5	0.1,0.8	0.1,0.5	1.7,3.0	16.7,35.5	13.2,22.7	16.6,21.5	4.5,7.9	35.2,45.2	8.7,11.9

* TC: trading centre; Markets: markets in Kampala City

The proportions of tomato growers selling to a nearby trading centre in peri-urban areas (5.0%) was significantly lower than in rural areas (14.8%, x^2=17.2, df=1, p<0.001) but was not significantly different from in urban areas (2.0%, odds ratio=0.43, 95% CI: 0.05-1.96, p=0.37). The proportions of tomato growers selling to markets in Kampala were not significantly different among 3 levels of urbanicity (x^2=2,652.1, df=2, p=0.26, Table 3.6).

The proportion of vegetable growers selling to a nearby trading centre in peri-urban areas (30.3%) was significantly higher than urban (0.1%, x^2=268.8, df=1, p<0.001) and rural areas (6.9%, x^2=163.1, df=1, p<0.001). Similarly, the proportion of vegetable growers selling to markets in Kampala was higher in peri-urban areas (40.2%) than urban (6.1%, x^2=214.6, df=1, p<0.001) and rural areas (x^2=193.4, df=1, p<0.001).

3.3.2. Comparison of urban, peri-urban and rural livestock farming

3.3.2.1. Proportions of LC1s with livestock

Table 3.7 shows the percentages of the LC1s keeping each livestock species in the different levels of urbanicity. In the interviews with the LC1 leaders, the number of the households keeping each livestock species was asked but the number of households keeping multiple livestock species were not asked. Therefore, the total number of households keeping any type of livestock was not ascertained.

The proportion of LC1s keeping improved and cross breed cattle in urban areas (mean=0.50) was significantly lower than peri-urban and rural areas (mean=1.00, $p<0.001$). The proportion of LC1s keeping indigenous cattle in peri-urban areas (mean=0.91) was significantly higher than in urban areas (mean=0.40, $p=0.001$), but was not significantly different from rural areas (mean=1.00, $p=0.174$). The proportion of LC1s keeping any breed of cattle in urban areas (mean=0.64) was significantly lower than in peri-urban and rural areas (mean=1.00, $p=0.002$). The proportion of LC1s keeping pigs in urban areas (mean=0.50) was significantly lower than in peri-urban and rural areas (mean=1.00, $p<0.001$). The proportion of LC1s keeping goats in urban areas (mean=0.69) was significantly lower than in peri-urban and rural areas (mean=1.00, $p<0.0001$). The proportion of LC1s keeping sheep in peri-urban areas (mean=0.64) was significantly higher than in urban areas (mean=0.13, $p=0.001$), but was not significantly different from rural areas (mean=0.69, $p=0.792$). The proportion of LC1s keeping broilers in peri-urban areas (mean=1.00) was significantly higher than in urban areas (mean=0.52, $p=0.001$) and in rural areas (mean=0.50, $p=0.001$).

Table. 3.7 Percentage of LC1s with livestock in the Kampala economic zone

	Urban	Peri-urban	Rural
Total LC1s	48	11	16
Improved breed cattle	24	11	16
Percent (95% CI)	50.0 (35.2-64.8)	100 (76.2-100)	100 (82.9-100)
Indigenous breed cattle	19	10	16
Percent (95% CI)	39.6 (25.8-54.7)	90.9 (58.7-99.8)	100 (82.9-100)
Any breed of cattle	29	11	16
Percent (95% CI)	60.4 (45.3-74.2)	100 (76.2-100)	100 (82.9-100)
Pig	24	11	16
Percent (95% CI)	50.0 (35.2-64.8)	100 (76.2-100)	100 (82.9-100)
Goats	33	11	16
Percent (95% CI)	68.8 (53.7-81.3)	100 (76.2-100)	100 (82.9-100)
Sheep	6	7	11
Percent (95% CI)	12.5 (4.8-25.2)	63.6 (30.8-89.1)	68.8 (41.3-89.0)
Broiler	25	11	8
Percent (95% CI)	52.1 (37.2-66.7)	100 (76.2-100)	50.0 (24.7-75.3)
Layer	26	11	75
Percent (95% CI)	54.2 (39.2-68.6)	100 (76.2-100)	75.0 (47.6-92.7)
Indigenous chicken	38	11	16
Percent (95% CI)	79.2 (65.0-89.5)	100 (76.2-100)	100 (82.9-100)

The proportion of LC1s keeping layers in peri-urban areas (mean=1.00) was also significantly higher than in urban areas (mean=0.54, p=0.001) and in rural areas (mean=0.75, p=0.002). The proportion of LC1s keeping indigenous chicken in urban

areas (mean=0.79) was significantly lower than in peri-urban and rural areas (mean=1.00, *p*=0.002).

3.3.2.2. Proportions of households keeping livestock

Table 3.8 shows a summary of the households keeping each livestock species in the 75 LC1s. Table 3.8 shows total numbers of households in the LC1s in each urbanicity category. Fig 3.5 compares the proportions of households keeping livestock among the three urbanicity groups with the variances among LC1s weighed.

The proportion of households keeping improved or cross breed cattle in peri-urban LC1s (mean=0.045) was significantly higher than urban LC1s (mean=0.003, *p*<0.001), but was not significantly different from rural LC1s (mean=0.037, *p*=0.623, Fig 3.5a (A)). However, the proportion of households keeping indigenous breed cattle in peri-urban LC1s (mean=0.022) was significantly higher than urban LC1s (mean=0.002, *p*<0.001), and was significantly lower than rural LC1s (mean=0.108, *p*<0.001, Fig 3.5a (B)). The proportion of households keeping cattle of any breed in peri-urban LC1s (mean=0.066) was significantly higher than urban LC1s (mean=0.005, p<0.001), and was significantly lower than rural LC1s (mean=0.145, *p*=0.009, Fig 3.5a (C)).

The proportion of households keeping pigs in peri-urban LC1s (mean=0.164) was significantly higher than urban LC1s (mean=0.014, *p*=0.001) but was not significantly different from rural LC1s (mean=0.160, *p*=0.968). The proportion keeping pigs in urban LC1s was significantly lower than rural LC1s (*p*=0.009, Fig 3.5a (D)).

Table. 3.8 Summary of households keeping livestock in the Kampala economic zone

	Urban	Peri-urban	Rural
Number of households	36,184	5,294	3,484
Improved breed cattle	109	237	129
Percentage (95% CI)	0.3 (0.2-0.4)	4.5 (3.9-5.1)	3.7 (3.1-4.4)
Indigenous breed cattle	75	112	377
Percentage (95% CI)	0.2 (0.2-0.3)	2.1 (1.7-2.5)	10.8 (9.8-11.9)
Any breed of cattle	184	349	506
Percentage (95% CI)	0.5 (0.4-0.6)	6.6 (6.0-7.4)	14.5 (13.4-15.7)
Pig	503	869	557
Percentage (95% CI)	1.4 (1.3-1.5)	16.4 (15.4-17.4)	16.0 (14.8-17.2)
Goats	238	153	335
Percentage (95% CI)	0.7 (0.6-0.7)	2.9 (2.5-3.4)	9.6 (8.7-10.6)
Sheep	13	38	51
Percentage (95% CI)	0.04(0.02-0.06)	0.7 (0.5-1.0)	1.5 (1.1-1.9)
Broiler	890	148	43
Percentage (95% CI)	2.5 (2.3-2.6)	2.8 (2.4-3.3)	1.2 (0.9-1.7)
Layer	264	68	51
Percentage (95% CI)	0.7 (0.6-0.8)	1.3 (1.0-1.6)	1.5 (1.1-1.9)
Indigenous chicken	5,294	3,128	2,490
Percentage (95% CI)	14.6 (14.3-15.0)	59.1 (57.7-60.4)	71.5 (69.9-72.9)
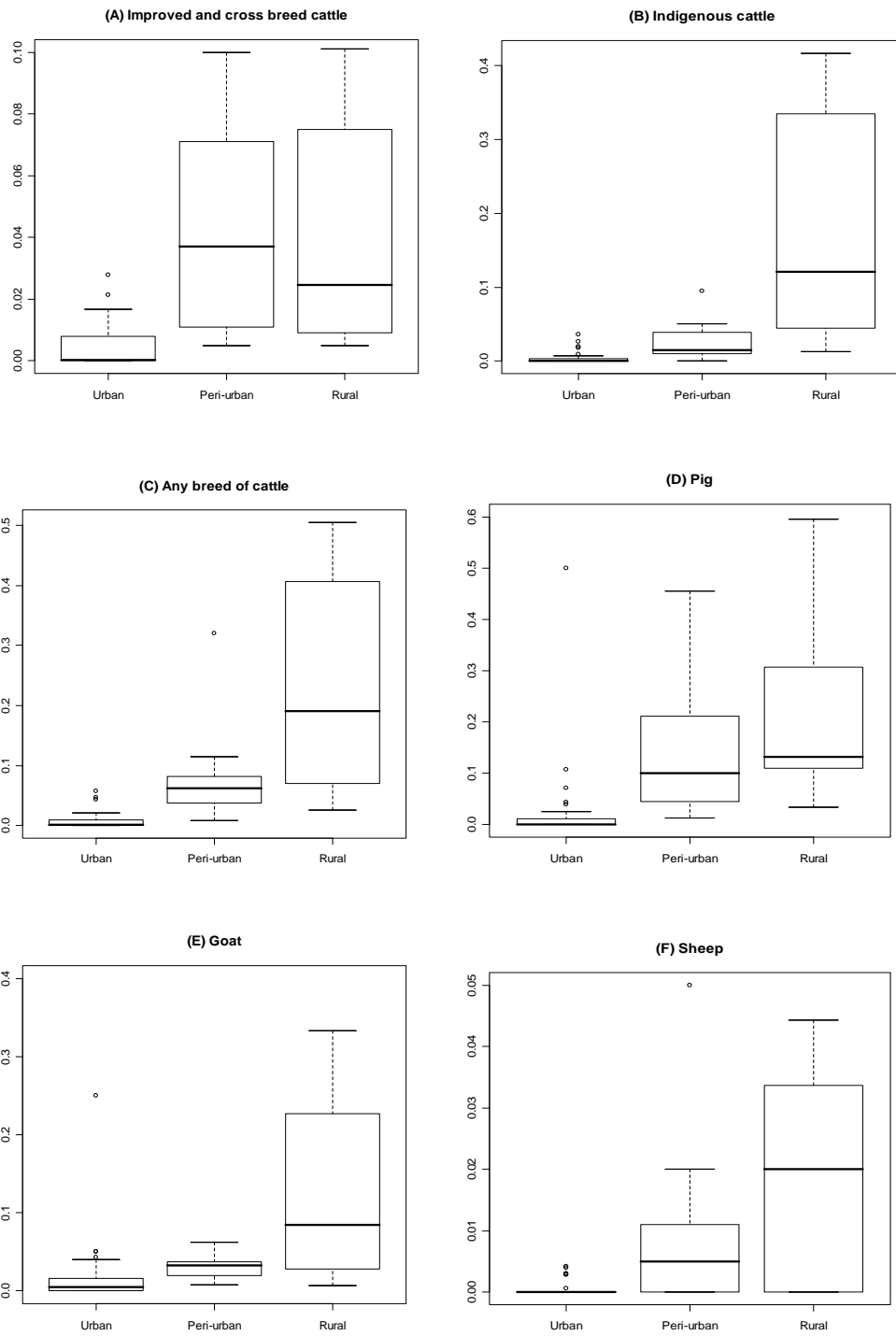
Fig. 3.5a Box and whisker plots showing proportions of households keeping livestock in urban, peri-urban and rural areas of the Kampala economic zone; horizontal lines shown are median, 25th and 75th percentiles, and 1.5 times interquartile range.

The proportion of households keeping goats in peri-urban LC1s (mean=0.029) was significantly higher than urban LC1s (mean=0.007, p=0.005), and was significantly lower than rural LC1s (mean=0.096, p=0.012, Fig 3.5a (E)).

The proportion of households keeping sheep in peri-urban LC1s (mean=0.007) was significantly higher than urban LC1s (mean=0.0004, p<0.01) but was not significantly different from rural LC1s (mean=0.015, p=0.125, Fig 3.5a (F)).

The proportions of households keeping broiler birds were not significantly different among urban (mean=0.025), peri-urban (mean=0.028) and rural LC1s (mean=0.012, p=0.607, Fig 3.5b (G)).

Similarly, the proportions of households keeping layer birds were not significantly different among urban (mean=0.007), peri-urban (mean=0.013), and rural LC1s (mean=0.015, p=0.41, Fig 3.5b (H)).

The proportion of households keeping indigenous chicken in peri-urban LC1s (mean=0.591) was significantly higher than urban LC1s (mean=0.146, p<0.01) but was not significantly different from rural LC1s (mean=0.715, p=0.411). The proportion in urban LC1s was significantly lower than rural (p<0.001, Fig 3.5b (I)).
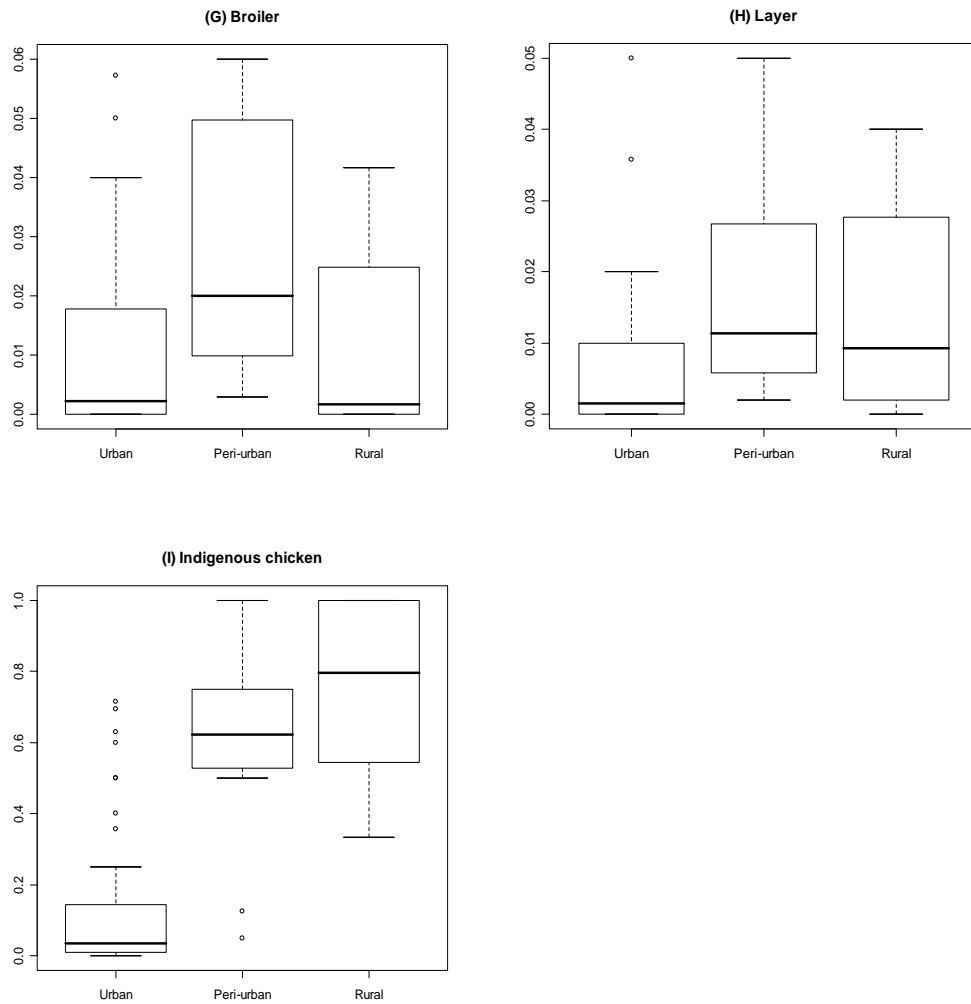
Fig 3.5b Box and whisker plots showing proportions of households keeping livestock in urban, peri-urban and rural areas of the Kampala economic zone; horizontal lines shown are median, 25th and 75th percentiles, and 1.5 times interquartile range.

3.3.2.3. Ranking popularity of livestock species

Table 3.9 shows the ranks of popular livestock species in 75 LC1s. Indigenous chicken was the most popular livestock species. Commercial livestock species (pig and broiler) occupied the second and third ranks. The least popular livestock species was sheep. A proportion of one livestock species was significantly different among all species (x^2=47,911.0, df=7, p<0.001), and paired proportions of neighbouring ranks were significantly different; indigenous chicken and pig (x^2=7329.3, df=1, p<0.001), pig and broiler (x^2=246.5, df=1, p<0.001), broiler and goats (x^2=70.7, df=1, p<0.001), goats and indigenous cattle (x^2=20.4, df=1, p<0.001), indigenous cattle and improved and cross breed cattle (x^2=7.5, df=1, p=0.006), improved and cross breed cattle and layer (x^2=9.7, df=1, p=0.002) and layer and sheep (x^2=162.5, df=1, p<0.001)

Table. 3.9 Ranks of popular livestock species in 75 LC1s

	Households (total 44,962)	Percentage	Rank
Indigenous chicken	10,912	24.3	1
Pig	1,929	4.3	2
Broiler	1,081	2.4	3
Goats	726	1.6	4
Indigenous breed cattle	564	1.3	5
Improved and cross breed cattle	475	1.1	6
Layer	383	0.9	7
Sheep	102	0.2	8

3.3.2.4. Herd (farm) size

Herd size was not significantly different among urban, peri-urban and rural areas for all livestock species (improved and cross breed cattle, indigenous cattle, pigs, goats, sheep, broiler, layer and indigenous chicken); the slopes of the linear relationship between log number of farms and farm size (number of animals or birds) fitted by GLM with Poisson errors did not significantly differ among three urbanicity groups. However, there was a very large commercial pig farm in one peri-urban area (farm size: number of pigs - 250) and two very large herds of goats in peri-urban areas (herd sizes: 150 and 200). Table 3.10 shows the geometric means of farm size in urban, peri-urban and rural areas for the livestock species.

Table. 3.10 Geometric means of farm size in urban, peri-urban and rural areas

	Urban	Peri-urban	Rural
Improved and cross breed cattle	2.87	2.81	1.95
Indigenous cattle	3.29	2.68	2.21
Pigs	3.55	1.90	2.83
Goats	3.12	2.88	2.47
Sheep	3.37	2.72	2.13
Broiler	132.7	170.2	217.7
Layer	238.2	245.8	262.2
Indigenous chicken	4.31	7.51	5.28

3.3.2.5. Large-scale farms

Table 3.11 shows the percentages of large-scale farms for each livestock species. The percentages of large-scale farms among improved and cross breed cattle farms were not significantly different among urban, peri-urban and rural areas (x^2=3.699, df=2, p=0.157).

There were no large-scale indigenous breed cattle farms in peri-urban areas. The percentages of large-scale indigenous breed cattle farms were not significantly different between urban and rural areas (odds ratio=0.098 (95%CI: 0.002-1.903), p=0.073).

The percentage of large-scale pig farms in peri-urban areas was not significantly different from rural areas (x^2=0.38, df=1, p=0.54), nor urban areas (Fisher's exact test, odds ratio 0.77 (95% CI: 0.17 - 2.8), p=0.78).

The percentage of large-scale broiler farms in peri-urban areas (8.8%) was significantly higher than in urban (3.1%, x^2=9.2, df=1, p=0.002), but was not significantly different from rural areas (14.0%, odds ratio 0.6 (95% CI: 0.2-2.0), p=0.38).

The percentage of large-scale layer farms in peri-urban areas (27.9%) was significantly higher than in urban areas (8.3%, x^2=19.2, df=1, p<0.001), but not significantly different from rural areas (23.5%, x^2=0.29, df=1, p=0.59). There were no large-scale indigenous chicken farms (data is not shown in Table 3.11).

Table. 3.11 Percentages of large-scale livestock farms

	Urban	Peri-urban	Rural
Improved and cross cattle farm	109	237	129
Large scale farms	4	20	6
Percentage (95% CI)	3.7 (1.0-9.1)	8.4 (5.7-12.7)	4.7 (1.7-9.8)
Indigenous breed cattle farm	75	112	377
Large scale farm	2	0	1
Percentage (95% CI)	2.7 (0.3-9.7)	0 (0.0-2.6)	0.3 (0.0-1.5)
Pig farm	503	869	557
Large scale farm	4	9	4
Percentage (95% CI)	0.8 (0.2-2.0)	2.0 (0.5-2.0)	0.7 (0.2-1.8)
Goat farm	238	153	335
Large scale farm	2	3	0
Percentage (95% CI)	0.8 (0.1-3.0)	2.0 (0.4-5.6)	0 (0.0-0.9)
Sheep farm	13	38	51
Large scale farm	1	0	0
Percentage (95% CI)	7.7 (0.2-36.0)	0 (0.0-7.6)	0 (0.0-5.7)
Broiler farm	890	148	43
Large scale farm	28	13	6
Percentage (95% CI)	3.1 (2.1-4.5)	8.8 (4.8-14.6)	14.0 (5.3-27.9)
Layer farm	264	68	51
Large scale farm	22	19	12
Percentage (95% CI)	8.3 (5.3-12.3)	27.9(17.7-40.1)	23.5 (12.8-37.5)

3.3.2.6. Animal density against human density

Fig 3.6 shows the number of animals (birds) per thousand households in urban, peri-urban, and rural areas. The appropriate measurement of animal density against human density is the number of animals (birds) per person. However, as population data in LC1s could not be obtained from interview, number of animals per thousand households was calculated instead.

The number of improved and cross breed cattle per thousand households was not significantly different between peri-urban LC1s (mean=144.5) and rural LC1s (mean=78.0, p=0.285). Urban LC1s were not compared with peri-urban and rural LC1s because 50% of urban LC1s did not have cattle, and these data could not be transformed. However, as the previous statistics had already shown that the proportion of households keeping cattle in urban areas were significantly lower than in peri-urban and rural LC1s, and that the farm size (animals/farm) in urban areas was not significantly different from the other areas, the number of improved and cross breed cattle per one thousand households in urban areas was significantly lower than in peri-urban and rural areas (Fig 3.6a (A)).
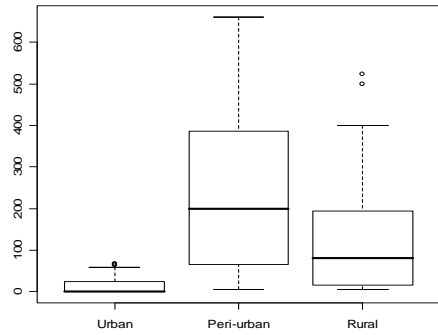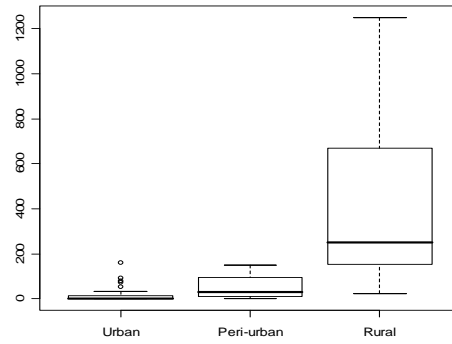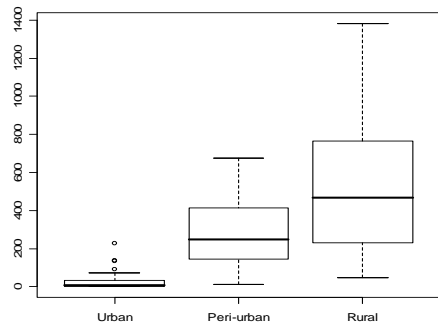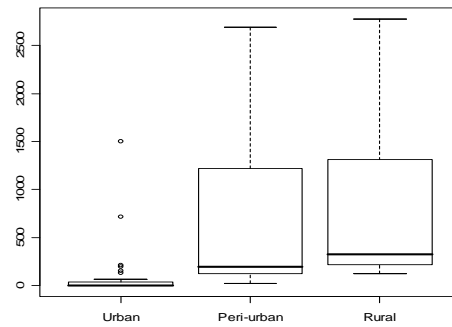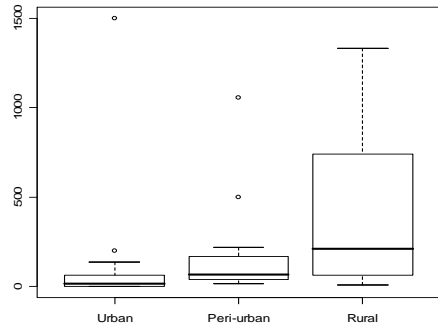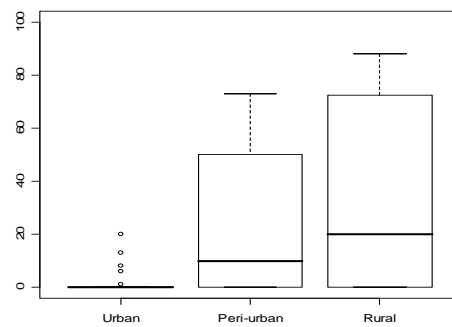
Fig. 3.6a Box and whisker plots showing the number of animals per thousand households in urban, peri-urban and rural areas of the Kampala economic zone; horizontal lines shown are median, 25th and 75th percentiles, and 1.5 times interquartile range.

The number of indigenous breed cattle per thousand households in peri-urban LC1s was significantly lower than in rural LC1s and the density of this type of cattle in urban areas was very low as shown in Fig 3.6a (B). The number of any breed of cattle per thousand households was not significantly different between peri-urban LC1s (mean=238.5) and rural LC1s (mean=444.4, p=0.091, Fig 3.6a (C)). The number of improved and cross breed cattle per thousand households in urban LC1s was significantly lower than in peri-urban and rural LC1s.

Similarly, the number of pigs per thousand households in urban LC1s was significantly lower than peri-urban and rural LC1s. The number was not significantly different between peri-urban LC1s (mean=330.9) and rural LC1s (mean=452.1, p=0.520, Fig 3.6a (D)).

The number of goats per thousand households in urban LC1s also was significantly lower than in peri-urban and rural LC1s by same reason. The number was not significantly different between peri-urban LC1s (mean=88.4) and rural LC1s (mean=198.1, p=0.183, Fig 3.6a (E)). The number of sheep per thousand households was very low in all urbanicity groups especially in urban areas (Fig 3.6a (F)).

The number of broiler birds per thousand households in peri-urban LC1s was obviously higher than in urban LC1s and rural LC1s (Fig 3.6b (G)).

The number of layer birds per thousand households in peri-urban LC1s was obviously higher than in urban LC1s but not obviously different from rural LC1s (Fig 3.6b (H)).

The number of indigenous chicken per thousand households in urban LC1s was significantly lower than in peri-urban and rural LC1s as with improved and cross breed cattle. The number of indigenous chicken per thousand households was not significantly different between peri-urban LC1s (mean=3,951.1) and rural LC1s (mean=4,159.3, p=0.860, Fig 3.6b (I)).

(G) Broiler

(H) Layer

(I) Indigenous chicken
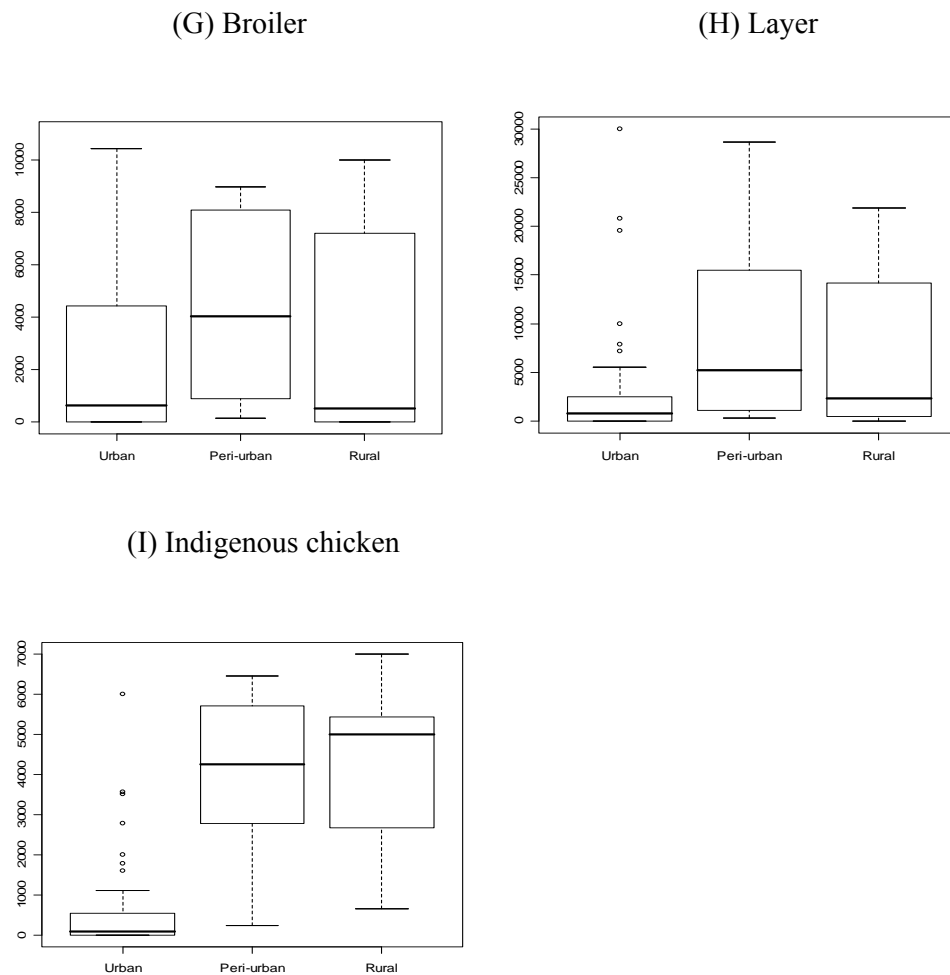
Fig 3.6b Box and whisker plots showing the number of birds per thousand households in urban, peri-urban and rural areas of the Kampala economic zone; horizontal lines shown are median, 25th and 75th percentiles, and 1.5 times interquartile range.

3.3.2.7. Sales destinations

Table 3.12 shows sales destinations of livestock and their products in the Kampala economic zone. The category 'improved breed cattle farm' shows only milk sales; sales of cattle to abattoirs were included in the category 'cattle farm of any breed'. Almost all improved and cross breed cattle farms sold milk to nearby trading centres and neighbours (Table 3.12a). Interviews with LC1 leaders showed that the modes of milk sales within LC1s were either direct purchase at the farm gate or a man selling with milk container (can or plastic) on a bicycle. In many cases, dairy farms made contracts with customers monthly, and delivered milk daily. One rural LC1 leader answered that children of dairy farmers in his area delivered milk by walking with plastic containers. The 11 urban farms which were not selling milk to nearby trading centres or neighbours were selling to large contract customers, such as police quarters, hotels, school canteens, and Nakasero Market (a large market within Kampala City). The percentage of improved and cross breed cattle farms selling milk to outside trading centres in peri-urban areas (27.0%) was significantly higher than in urban (10.1%, x^2=12.6, df=1, p<0.001) and rural areas (9.3%, x^2=15.9, df=1, p<0.001, Table 3.12a).

The percentage of 'any breed' of cattle farms selling cattle to urban abattoirs in peri-urban areas (34.7%) was significantly lower than in urban areas (56.0%, x^2=22.5, df=1, p<0.001), and significantly higher than in rural areas (13.2%, x^2=55.3, df=1, p<0.001). The percentage of 'any breed' of cattle farms selling cattle to peri-urban abattoirs in peri-urban areas (98.6%) was significantly higher than in urban areas (53.8%, x^2=172.0, df=1, p<0.001). All farms in rural areas sold cattle to peri-urban abattoirs (Table 3.12a, Fig 3.7).

Table. 3.12a Sales destinations of the livestock products in the Kampala economic zone

	Urban	Peri-urban	Rural
Improved breed cattle farm	109	237	129
Nearby TC, neighbours	98	237	129
Percentage (95% CI)	89.9 (82.7-94.6)	100 (98.7-100)	100 (97.7-100)
Outside trading centre	11	64	12
Percentage (95% CI)	10.1 (5.1-17.3)	27.0 (21.5-33.1)	9.3 (4.9-15.7)
Cattle farm of any breed	184	352	506
Urban abattoirs	103	121	67
Percentage (95% CI)	56.0 (48.5-63.3)	34.7 (29.7-39.9)	13.2 (10.4-16.5)
Peri-urban abattoirs	99	344	506
Percentage (95% CI)	53.8 (46.3-61.2)	98.6 (96.7-99.5)	100 (99.4-100)
Pig farm	503	869	557
Nearby TC, neighbours	438	719	427
Percentage (95% CI)	87.1 (83.8-89.9)	82.7 (80.1-85.2)	76.7 (72.9-80.1)
Outside trading centre	393	760	363
Percentage (95% CI)	78.1 (74.3-81.7)	87.5 (85.1-89.6)	65.2 (61.1-69.1)
Wambizi Abattoir	26	39	0
Percentage (95% CI)	5.2 (3.4-7.5)	4.5 (3.2-6.1)	0 (0.0-0.5)
Goat farm	238	153	335
Traders distributing in Kampala	84	27	87
Percentage (95% CI)	35.3 (29.2-42.7)	17.6 (12.0-24.6)	26.0 (21.4-31.0)
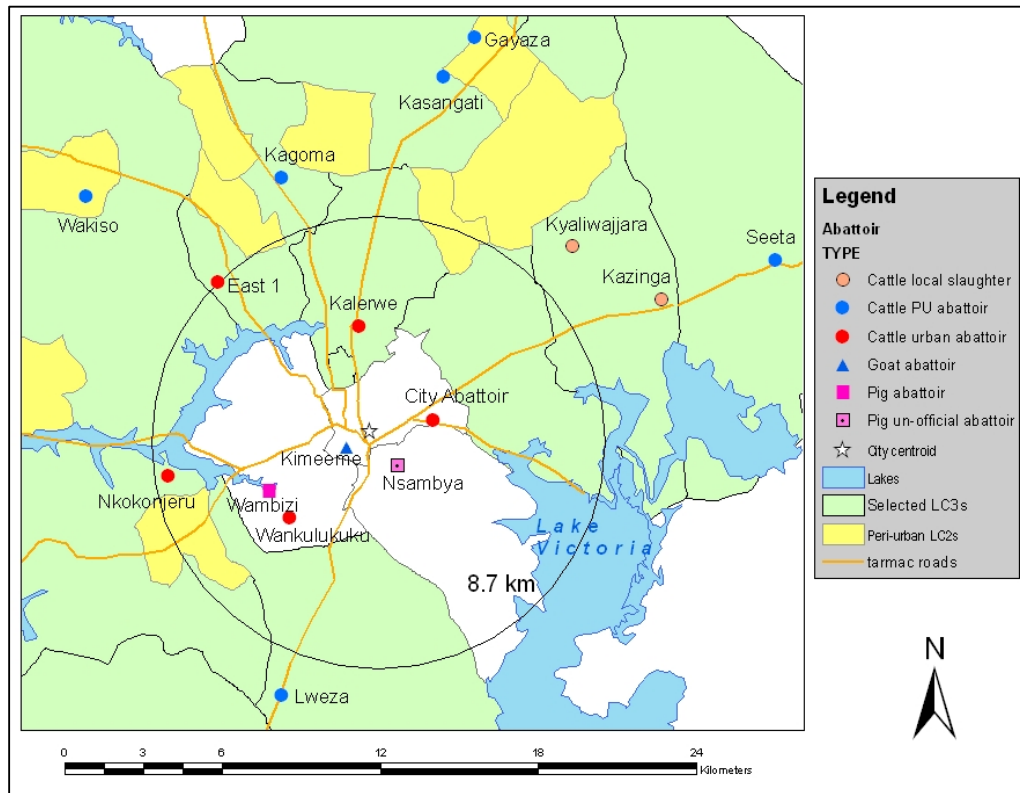
Fig. 3.7 Map of cattle, pig, and goat abattoirs in and around Kampala City. Local slaughter: local slaughter places.

The percentage of pig farms selling pigs to a nearby trading centre and neighbours in peri-urban areas (82.7%) was significantly lower than in urban (87.1%, x^2=4.5, df=1, p=0.033) and significantly higher than in rural areas (76.7%, x^2=7.9, df=1, p=0.005, Table 3.12a). The percentage of pig farms selling pigs to traders distributing to trading centres in Kampala was significantly higher in peri-urban areas (87.5%) than in urban (78.1%, x^2=20.7, df=1, p<0.001) and rural LC1s (65.2%, x^2=100.8, df=1, p<0.001). According to LC1 leaders, pigs were slaughtered at pen-side and distributed to trading centres by traders, or taken alive to nearby trading centres and slaughtered at butcheries in all levels of urbanicity. In Kampala, there was only one

pig abattoir, Wambizi where a veterinarian inspected pig carcases. The percentages of pig farms selling to Wambizi abattoir in urban (5.2%) and peri-urban areas (4.5%) were very low, and were not significantly different (x^2=0.33, df=1, p=0.57); no rural pig farms sold to this abattoir. A few LC1 leaders mentioned that there were some local pig abattoirs in and around Kampala. Veterinary meat inspection at such abattoirs and detailed pork distribution networks were not studied due to time limitations. One unofficial abattoir owner in Nsambia, central Kampala described that his pork was not inspected by a veterinarian (Fig 3.7).

The percentage of goat farms selling goats to traders distributing outside trading centres and abattoirs in peri-urban areas (17.6%) was significantly lower than in urban (35.3%, x^2=14.3, df=1, p<0.001) and rural areas (26.0%, x^2=4.1, df=1, p=0.044, Table 3.12a), and sale of goats was especially popular in urban areas. According to the LC1 leaders, the main purposes of goat farming were for home consumption for special occasions such as Christmas and Easter and as assets, especially for children's school fees. For home consumption, goats are slaughtered at butchers in trading centres or at home. Most of the traders carry goats to abattoirs, but a few butchers in trading centres slaughter goats without meat inspection by veterinarians. Kimeeme abattoir specialised in goats, but goats were more commonly slaughtered at cattle abattoirs (Fig 3.7).

When LC1 leaders were asked about the purpose of sheep keeping (about half of the studied LC1s) all respondents answered that it was to protect the household from evil spirits. At some point sheep can be consumed, however they were not regarded as a food animal.

Table 3.12b Sales destinations of the crops produced in the Kampala economic zone

	Urban	Peri-urban	Rural
Broiler farm	890	148	43
Nearby trading centre	806	133	32
Percentage (95% CI)	90.6	89.9	74.4
	(88.4-92.4)	(83.8-94.2)	(58.8-86.5)
Outside trading centres	746	132	21
Percentage (95% CI)	83.8	89.2	48.8
	(81.2-86.2)	(83.0-93.7)	(33.3-64.5)
Layer farm	264	68	51
Nearby trading centre	253	32	35
Percentage (95% CI)	95.8	47.1	68.6
	(92.7-97.9)	(34.8-59.6)	(54.1-80.9)
Outside trading centres	210	40	28
Percentage (95% CI)	79.5	58.8	54.9
	(74.2-84.2)	(46.2-70.6)	(40.3-68.9)

The percentage of broiler farms selling to a nearby trading centre in peri-urban areas (89.9%) was not significantly different from urban (90.6%, x^2=0.07, df=1, p=0.78) but significantly higher than in rural areas (74.4%, x^2=6.8, df=1, p=0.009, Table 3.12b). The percentage of broiler farms selling to outside trading centres in peri-urban areas (89.2%) was not significantly different from urban areas (83.8%, x^2=2.8, df=1, p=0.09), but significantly higher than in rural areas (48.8%, x^2=34.0, df=1, p<0.001).

The percentage of layer farms selling eggs to a nearby trading centre in peri-urban areas (47.1%) was significantly lower than in urban areas (95.8%, x^2=105.9, df=1, p<0.001) and significantly higher than in rural areas (68.6%, x^2=5.5, df=1, p=0.019, Table 3.12b). The percentage of layer farms selling eggs to outside trading centres was significantly lower in peri-urban areas (58.8%) than in urban areas (79.5%, x^2=12.5, df=1, p<0.001), but not significantly different from that in rural areas (54.9%, x^2=0.2, df=1, p=0.67). The purpose of indigenous chicken keeping was mainly for home consumption.

3.3.3. Urban agriculture

3.3.3.1. Urban crop production

Table 3.13 shows the numbers and percentages of urban households engaged in crop production by development types. The most popular product was plantain, with maize, green leafy vegetables, and tomato following it in order. Crops in urban areas were almost exclusively produced in middle-income residential areas and trading centres. There were a few households growing maize and vegetables in slum areas. None of the households in city centre produced crops.

For all types of crop, the percentages of households growing the product were significantly higher in middle-income residential areas than trading centres: plantain (x^2=1,946.8, df=1, p<0.001), maize (x^2=118.6, df=1, p<0.001), tomato (x^2=115.6, df=1, p<0.001) and green leafy vegetables (x^2=1440.1, df=1, p<0.001).

Table. 3.13 Urban households engaged in crop production

	High income	Middle income	Slum	Trading centre	City centre
Number of households	800	9,560	3,860	21,714	250
Plantain	1	1,781	0	806	0
Percentage (95% CI)	0.1 (0.0-0.7)	18.6 (17.9-19.4)	0 (0.0-0.1)	3.7 (3.5-4.0)	0 (0.0-1.2)
Maize	1	560	10	701	0
Percentage (95% CI)	0.1 (0.0-0.7)	5.9 (5.4-6.3)	0.3 (0.1-0.5)	3.2 (3.0-3.5)	0 (0.0-1.2)
Tomato	0	75	0	16	0
Percentage (95% CI)	0 (0.0-0.4)	0.8 (0.6-1.0)	0 (0.0-0.1)	0.1 (0.0-0.1)	0 (0.0-1.2)
Green leafy vegetables	0	723	40	61	0
Percentage (95% CI)	0 (0.0-0.4)	7.6 (7.0-8.1)	1.0 (0.7-1.4)	0.3 (0.2-0.4)	0 (0.0-1.2)

3.3.3.2. Urban livestock farming

Table 3.14 shows the numbers and percentages of urban households keeping each livestock species by development type. Livestock farming was less popular than crop production (especially production of plantain and maize) in urban areas of Kampala, except for indigenous chicken. As with crop production, livestock production in urban areas was mainly carried out in middle-income residential areas and trading centres.

Improved and cross breed cattle were the only livestock species where the percentage of households keeping cattle was highest in high income residential areas (0.8%) although it was not significantly greater than in middle income residential areas (0.6%, x^2=0.44, df=1, p=0.5).

The percentage of households keeping livestock was significantly higher in middle income residential areas than trading centres for: improved and cross breed cattle (x^2=23.3, df=1, p<0.001), indigenous breed cattle (x^2=35.1, df=1, p<0.001), goats (x^2=20.2, df=1, p<0.001), and layers (x^2=45.9, df=1, p<0.001). This presumably reflects the larger amount of space available for farming in middle income residential areas. On the other hand, the percentage of households keeping livestock was significantly higher in trading centres than in middle income residential areas for: pigs (x^2=11.5, df=1, p=0.001), broilers (x^2=49.2, df=1, p<0.001), and indigenous chicken (x^2=137.1, df=1, p<0.001). The reasons for significant differences in pig and broiler keeping might be that trading centre residents were keener on quick returns and pork and broiler meat is largely consumed at restaurants and pubs in trading centres.

Table. 3.14 Numbers and percentages of urban households keeping livestock by development types

	High income	Middle income	Slum	Trading centre	City centre
Households	800	9,560	3,860	21,714	250
Improved and cross breed cattle	6	54	0	49	0
Percentage (95% CI)	0.8 (0.3-1.6)	0.6 (0.4-0.7)	0 (0.0-0.1)	0.2 (0.2-0.3)	0 (0.0-1.2)
Indigenous breed cattle	0	47	2	29	0
Percentage (95% CI)	0 (0.0-0.4)	0.5 (0.4-0.7)	0.05 (0.0-0.2)	0.1 (0.1-0.2)	0 (0.0-1.2)
Any breed of cattle	6	101	2	78	0
Percentage (95% CI)	0.8 (0.3-1.6)	1.1 (0.9-1.3)	0.05 (0.0-0.2)	0.4 (0.3-0.4)	0 (0.0-1.2)
Pig	7	116	4	376	0
Percentage (95% CI)	0.9 (0.4-1.8)	1.2 (1.0-1.5)	0.1 (0.0-0.3)	1.7 (1.6-1.9)	0 (0.0-1.2)
Goats	8	93	23	114	0
Percentage (95% CI)	1.0 (0.4-2.0)	1.0 (0.8-1.2)	0.6 (0.4-0.9)	0.5 (0.4-0.6)	0 (0.0-1.2)
Sheep	0	4	0	9	0
Percentage (95% CI)	0 (0.0-0.4)	0.04(0.01-0.11)	0 (0.0-0.1)	0.04(0.02-0.08)	0 (0.0-1.2)
Broiler	7	175	1	707	0
Percentage (95% CI)	0.9 (0.4-1.8)	1.8 (1.6-2.1)	0.03 (0.0-0.1)	3.3 (3.0-3.5)	0 (0.0-1.2)
Layer	3	130	0	131	0
Percentage (95% CI)	0.4 (0.1-1.1)	1.4 (1.1-1.6)	0 (0.0-0.1)	0.6 (0.5-0.7)	0 (0.0-1.2)
Indigenous chicken	16	1,236	62	3,970	10
Percentage (95% CI)	2.0 (1.1-3.2)	12.9 (12.3-13.6)	1.6 (1.2-2.1)	18.3 (17.8-18.8)	4.0 (1.9-7.2)

In order to assess dependence on livestock farming in slum areas, slums were compared with trading centres with similar functions as the destinations of immigrants from rural areas (as described in Chapter 2, section 2.3.2). The percentages of households keeping livestock in slum areas were significantly lower than in trading centres for: pigs (x^2=59.3, df=1, p<0.001), broilers (x^2=127.0, df=1, p<0.001) and indigenous chicken (x^2=686.4, df=1, p<0.001). The percentages for goats (x^2=0.3, df=1, p=0.58) and indigenous cattle (odds ratio=0.39, 95% CI: 0.04-1.5, p=0.2) were not significantly different. There were no households keeping improved or cross breed cattle, sheep or layers in slum areas.

There was one chicken hatchery in middle income residential areas (data not shown in Table 3.14). Among all livestock species, indigenous chicken was the most popular, and remarkably, ten households in the city centre kept indigenous chicken.

3.4. Discussion

This survey has highlighted the characteristics of urban and peri-urban agriculture of the Kampala economic zone by comparing these areas with rural counterparts in an objective manner.

3.4.1. Characteristics of urban agriculture in Kampala

Urban crop production in Kampala is largely carried out to provide food security, and a significantly lower proportion of households were engaged in crop production when compared with peri-urban areas. However, urban agriculture was a source of perishable crops consumed by city populations; 25.3% of tomato growers and 6.1% of leafy vegetable growers sold to the markets in Kampala. The percentages of households engaged in crop production (plantain 7.2%, maize 3.5%, tomato 0.3% and leafy vegetables 2.3% - a producer might grow more than one species) were not as high as those observed by Maxwell *et al*. (1995) who found that 33.9% of households in Kampala in 1995 grew crops, however these data included peri-urban areas.

In urban areas, middle income residential areas and trading centres were the main locations for crop production; crops were more widely grown in middle income residential areas than in trading centres. Maize and vegetables were grown in one slum area by a few households in an area under the electricity power lines where agricultural activities are illegal and the Electricity Board often destroys these crops (Kiguli 2003).

Urban livestock farming (cattle, pigs, goats, sheep and indigenous chicken) in

Kampala was undertaken to provide income with significantly smaller proportions of households engaged when compared with peri-urban areas. However, broilers and layers were kept by proportionally as many urban households as in peri-urban and rural areas; broiler was the second most popular livestock species in urban areas after indigenous chicken. Most of urban and peri-urban broiler farms were operated commercially targeting outside markets. Most urban layer farms were also operated for commercial purposes, and the sales of eggs to outside markets were more common than in peri-urban areas. A study in Kampala in 1994 found that 70% of the poultry and eggs eaten in the city were produced there (Egziabher 1994); the situation was still the same in 2005 as the present study has shown. Extensive farming of indigenous chicken was the most popular agricultural activity (24.3% of total households) in order to provide food security; this finding is consistent with various studies in Kampala (Atukunda 2003; Maxwell 1999; Maxwell 1995). Goats were sold to traders distributing in Kampala more than in peri-urban areas, but the main purpose of goat farming was home consumption for special occasions. Herd (farm) sizes in urban areas were not significantly different from peri-urban and rural areas for all livestock species, except for large scale broiler and layer farms where there were lower proportions in urban areas compared to peri-urban areas. Pigs were the second most popular species following indigenous breed chicken in urban areas; the percentage of pig keeping households was lower than in peri-urban and rural areas, but a higher proportion of farmers kept pigs for income generation in urban areas. This finding differs from the case study by Atukunda (2003) who showed that the popular livestock species for income generation were poultry and dairy cattle in a single urban parish (Atukunda 2003). However, the present study is more robust because a cluster analysis of randomly selected 48 urban LC1s was used while only

one parish was studied in each urbanicity category by Atukunda (2003).

3.4.2. Characteristics of peri-urban agriculture in Kampala

The most popularly grown crops in peri-urban Kampala were plantain and maize (62.7 and 45.8% of total households) which provided food security. Peri-urban perishable crop production was mainly for income generation, unlike urban areas (17.6% of tomato and 40.2% of leafy vegetable growers sold to the markets in Kampala).

Peri-urban livestock farming was characterised by the significantly higher proportions of households keeping cattle, pigs, goats, sheep, and indigenous chicken than in urban areas, and a significantly higher proportion of dairy cattle and pig farmers sold to outside trading centres in Kampala than farmers in urban areas. The sale of milk and pigs to Kampala from peri-urban areas were also more common than among farmers in rural areas; peri-urban farmers were the main providers of milk and pigs to the Kampala economic zone. The proportions of households keeping indigenous breed animals such as indigenous cattle, goats and indigenous breed chicken in peri-urban areas were higher than urban areas, and lower than rural areas; as the level of urbanicity increased, the proportions decreased.

Livestock farming in peri-urban areas was not significantly more intensive than urban and rural areas, in terms of herd size for all livestock species. Intensive farming as a characteristic of peri-urban livestock farming was reported for dairy farming in Dar es Salaam (Sumberg 1997; Sumberg 1999), poultry and dairy farming

in Nairobi (Foeken 2000), poultry farming in Kumasi, Ghana (Adam 2001), poultry and pig farming in Accra, Ghana (Armar-Klemesu 2000), and dairy farming in Hubli-Dharwad, India (Brook 2000; Khan 1997). In the present study, a few extremely large farms were found in peri-urban areas; however, the statistics showed no significant differences among the three urbanicity groups with the majority of peri-urban livestock farms operating on a small scale.

The crops selected for this study were not necessarily the most popular for UPA in Kampala. The crops should have been selected on the basis of a literature review. However, as mentioned in the introduction (section 3.1.4), most of the relevant studies on this topic had yet to be published at the time of study design; the most relevant publication was published after this study was started (Kimeze 2005). Nevertheless, this limitation did not significantly affect the outcome of the study in defining the role of UPA.

3.4.3. Risk of zoonoses

The farming of livestock in urban and peri-urban areas and the selling of livestock products in an unregulated fashion could lead to a risk of zoonotic disease. Here, the risks of zoonoses are discussed from two viewpoints; firstly in terms of animal density against human density and secondly in relation to market chains.

Animal density in urban areas was significantly lower than peri-urban and rural areas in relation to human density for dairy cattle, any breed of cattle, pigs, goats, sheep, layer birds and indigenous breed chickens. Also, for all of these livestock species,

animal density in relation to human density was not significantly different between peri-urban and rural areas. Broiler was the only species for which animal density against human density was the highest in peri-urban areas. As areal measurements of the 75 LC1s studied were not obtained, further analysis taking into account spatial animal density (number of animals per area) was not possible. However from above results, the zoonotic risks from direct or close contacts were estimated to be lower in urban areas for all livestock species than in peri-urban and rural areas, with the one exception of broilers where the risks are the highest in peri-urban areas. Zoonotic risks from poultry were highest (in terms of animal density against human density) due to the popularity of chicken keeping in and around Kampala.

Unpasteurised milk may transmit brucellosis (Aiello & Mays 1998), bovine tuberculosis (Collins & Grange 1987), *Escherichia coli* o157:H7 (Arimi *et al.* 2005), *Salmonella enterica* (Merck Veterinary Manual. 2008) and the other milk borne diseases. This study revealed the existence of some informal milk sales directly from dairy farmers, or through milk distributors. To properly quantify zoonotic risks from raw contaminated milk consumption in Kampala, it would be necessary to carry out a holistic market chain study because urban areas cannot necessarily be defined as low-risk areas if contaminated raw milk is sold there via distribution routes taking milk from production areas outside Kampala.

According to the informal interviews with LC1 leaders in rural areas of Kampala, veterinarians inspected slaughtered cattle carcasses even in small local slaughter places. As cattle carcasses were inspected in all urban and peri-urban abattoirs, the zoonotic risks from beef were low; however, the risks cannot be ignored because the

destinations of meat rejected by veterinarians, and cooking practices in households were not known.

The risks of zoonoses from pork were very high in Kampala; only a few pig farmers were selling their pigs to the Wambizi abattoir, which is the only abattoir in Kampala inspected by veterinarians (Phiri 2002). Most pigs were slaughtered within LC1s where they were reared and the carcasses were distributed, without meat inspection, to trading centres and pubs serving roasted pork in Kampala. Inadequately cooked and uninspected pork carries the risk of *T. solium* taeniosis (with the larvae (cysticerci) becoming tapeworms in humans' intestines), and increases the risk of *T. solium* human cysticercosis by ingestion of eggs from adult tapeworms (Sarti *et al.* 1992). When the cysticerci lodge in the brain and spinal cord of humans, the condition known as neurocysticercosis (NCC) arises; the clinical signs are headache, epileptic seizures, blindness, mental disturbance and even death (Phiri *et al.* 2003; White 2000). Kisakye and Masaba (Kisakye & Masaba 2002; Phiri *et al.* 2003) reported pigs infected with *T. solium* in Uganda. Pork consumption is rapidly becoming popular in Uganda (Phiri 2002) and the associated risks of taeniosis and cysticercosis are evidently high in all areas of the city.

Brucella melitensis brucellosis is a zoonosis carried by goats, sheep and camels (Kyebambe 2005). The risks of zoonoses from goat meat were high in peri-urban and rural areas, because goats were consumed locally without veterinary inspection. Goats are slaughtered in urban and peri-urban abattoirs, and the meat is inspected by veterinarians there. However a few butchers slaughter goats in urban trading centres without meat inspection by veterinarians. As with beef, the destination of goat meat

rejected at inspection is largely unknown.

Poultry pose the largest zoonotic risk to the populations living in and around Kampala given the popularity of both intensive and extensive poultry farming. The case-fatality (CF) rate of H5N1 highly pathogenic avian influenza (HPAI) was recently estimated to 14-33% under pandemic conditions (Li *et al.* 2008). After the first outbreak in Africa in Kaduna, Nigeria, on 8th February 2006, seven other countries on the continent, Burkina Faso, Cameroon, Côte d'Ivoire, Djibouti, Egypt, Niger and Sudan, were infected within three months (Seck 2007). The risk of the infection with HPAI in urban and peri-urban populations in Kampala is clearly very high and it could post a serious health problem. Broiler chicken carcasses carry risks of enteritis caused by *Campylobacter jejuni* and *Campylobacter coli* (Williams 2008), *Listeria monocytogenes*, and salmonellosis (Merck Veterinary Manual 2008). In Senegal, a study showed indirect evidence of *Salmonella* transmission to humans from contaminated broiler meat (Cardinale *et al.* 2005). *Salmonella enteritidis*, a serovar of *Salmonella enterica*, can be present in perfectly normal looking eggs, and if these eggs are eaten raw or undercooked, the bacterium can cause abdominal cramps, and diarrhoea in humans (CDC 2005). *Salmonella enterica* may be transmitted to humans through contaminated drinking water, milk, meat and foods such as cake mixes that use contaminated ingredients, but poultry and eggs are particularly important sources of infection (Merck Veterinary Manual 2008). Humans acquire *Listeria monocytogenes* from contaminated food including poultry and its products (Merck Veterinary Manual 2008), and it can cause febrile gastroenteritis, perinatal infection, and systemic infections marked by central nervous system infections to humans (Drevets & Bronze 2008). Food market chains are important

factors in understanding zoonotic risks although they have not been considered in detail here. Only one market chain, for milk, was studied in detail, and is described later in Chapter 7.

3.4.4. Role of UPA in food security in Kampala

UPA was clearly important for food security in Kampala especially with crops and indigenous breed chicken in urban and peri-urban areas. UPA also had a significant role in income generation. Slum dwellers were not dependent for their food on agriculture but preferred to work at jobs in town where they could earn a living; moreover, the slum environment was too crowded to provide any suitable space for cultivation. In urban areas, agriculture was practised most commonly in middle income residential areas and trading centres.

Farming in urban areas is technically illegal or regulated by zoning in Kampala City (Ssemwanga 2002). However, if UPA were to be encouraged by changes in legislation, this would enhance the food security and reduce poverty of the inhabitants. The present study is in agreement with many studies on UPA that have suggested encouraging UPA with appropriate policy support to ensure the environmental sustainability (Davidson 1994; Kimeze 2005; Musimenta 1997; Nostrand van 1994; Nuwagaba 2002). 'Appropriate policy supports' should however include assessment of associated zoonotic risks, which are considered in the following chapters of this thesis.

4. Chapter 4 A survey of urban and peri-urban zoonoses affecting the human populations in the Kampala economic zone

4.1. Introduction

4.1.1. Aims

The aim of this chapter is to understand most important zoonotic diseases affecting urban and peri-urban human populations in the Kampala economic zone. Few studies have been carried out on zoonotic diseases in this area, and the present study attempts to determine which zoonoses affect the human population in this area by screening medical records of Mulago Hospital for all of zoonotic diseases.

4.1.2. Zoonoses in urban and peri-urban areas in developing countries

In developing countries, cities are rapidly expanding; by 2025 it is estimated that over 50% of the population in those countries will reside in or around cities (FAO 2002). To feed these growing city populations, urban and peri-urban agriculture (UPA) has become part of the development agenda (FAO 2000). UPA has important roles in employment, improvement of children's nutrition status (Maxwell 1995), food security (Ellis & Sumberg 1998; Sumberg 1999), and stability of food supply and prices (Mougeot 2000). However, UPA also carries risks of increased competition for resources (land, water, energy, and labour) (Drechsel *et al.* 1999), nutrient mining (Stoorvogel & Smaling 1990), and environmental and health hazards such as heavy metal contamination of soils and irrigation waters (Bellows 1999) and zoonotic diseases (Flynn 1999).

Zoonoses have been defined as "diseases and infections that are naturally transmitted between vertebrate animals and man" (WHO 1959). The list of 838 zoonotic pathogens is available in the Appendix of Taylor *et al.* (2001). Important zoonotic diseases/pathogens in peri-urban systems were identified by Perry *et al.* as *Brucella*

abortus, bovine tuberculosis, anthrax, *Brucella melitensis*, *Toxocara vitulorum*, and cysticercosis in the order of impact on the poor in developing countries, by the International Livestock Research Institute (ILRI) (Perry 2002).

Livestock farming in urban and peri-urban areas is characterised as landless livestock production systems, which is a large industry, involving many small-scale farmers and some large agri-businesses (Devendra 2005). Landless systems are defined as those where less than 10% of the dry matter consumed is produced on the farm where the livestock are located, and where annual average stocking rates are above 10 livestock units (1 LU= 1 cattle or buffalo or 8 sheep or goats) per hectare of agricultural land (Sere 1996). Important zoonoses may be related to the characteristics of livestock farming in the areas.

4.1.3. Zoonoses in urban and peri-urban areas of Kampala

A health impact assessment study of urban agriculture in Kampala was carried out supported by Canadian Aid (CIDA) which included a component on zoonoses (King'ori 2004). The studies indicated that brucellosis was widespread in livestock in both urban and peri-urban areas of Kampala (Lee-Smith 2006). Using the milk ring test (MRT), 44.4% (n=162) of the marketed milk samples in urban and peri-urban areas of Kampala were positive for antibodies against *Brucella*. In cattle, 42% (n=245) of the samples were positive for antibodies against *Brucella* using slow serum tube agglutination test (SAT) (Mwiine 2004). Milk samples were found to have high levels of antimicrobial residues (Lee-Smith 2006). Broad-spectrum antimicrobial residues were found in 13.9% of milk samples using the *Charm* Farm-960 test, and 13% of these were specifically positive for Beta-Lactam drugs

(Mwiine 2004).

There was a risk of *Escherichia coli* O157:H7 infection in the study areas. Two out of the 165 cattle serum samples taken were serologically confirmed to be *E. coli* O157:H7 (Mwiine 2004). A quantitative risk analysis on Shiga toxigenic *Escherichia coli* (STEC) revealed that two to three symptomatic STEC infections could be expected for every 10,000 unpasteurized milk portions consumed, with a possible range of 0 to 22 symptomatic cases (Grace 2008).

4.1.4. Burdens in human caused by the most significant zoonoses in Kampala

The disease burdens in humans caused by the four most common zoonotic diseases in Kampala (brucellosis, bovine tuberculosis, cysticercosis and gastrointestinal (GI) infections) are reviewed here.

4.1.4.1. Brucellosis

Brucellosis is caused by gram-negative bacilli, of the genus *Brucella* (*Brucella abortus, B. suis, B. melitensis and B. canis*) (Young 2000). The disease in cattle, water buffalo, and bison is caused almost exclusively by *B. abortus*. Brucellosis in goats and sheep is caused by *B. melitensis*, and in pigs and horses, by *B. suis*. Brucellosis in dogs is caused by *B. canis* although dogs are occasionally become infected with *B. abortus, B. suis,* and *B. melitensis* (Merck Veterinary Manual 2008). Brucellosis in humans is characterised by continued, intermittent or irregular fever, headache, weakness, profuse sweating, chills, arthralgia, depression, weight loss and generalised aching. Localised suppurative infections of organs, including the liver and spleen may occur. The disease may last for several days, months, or occasionally

a year or more if not adequately treated. Genitourinary involvement is reported in 2-20% of the cases, with orchitis and epididymitis most common. The case-fatality rate of untreated brucellosis is 2% or less and usually results from endocarditis caused by *B. melitensis* infection (Chin 2000). Reappearance and relapse of the symptoms are common, but the disease is curable using antibiotics. Conventional therapy for brucellosis in Uganda is oral doxycycline for 6 weeks and IM streptomycin for 2 weeks (Kyebambe 2005).

Generally speaking, human infection occurs through consumption of poorly prepared meat and dairy products in the form of milk, cheese and butter. Certain occupations such as veterinarians, butchers, abattoir workers, meat inspectors, farmers and those working in meat packing and dairy processing industries are known to be at a greater risk (Kunda 2007).

4.1.4.2. Bovine tuberculosis

Bovine tuberculosis (TB) has important socio-economic and public health impacts. Bovine TB is caused by *Mycobacterium bovis*. Infection of humans with *M bovis* may occur by inhalation of aerosols or through consumption of milk contaminated with the bacilli. Although contaminated milk is the usual source of infection amongst town dwellers, farm workers often acquire lung disease directly by inhalation (Collins & Grange 1987; Hedvall 1941). Adult humans infected by the respiratory route through contact with *M. bovis* aerosols from infected cattle develop typical pulmonary tuberculosis (Wedlock *et al.* 2002). The highest risk group are individuals with concomitant human immunodeficiency virus (HIV)/acquired immunodeficiency syndrome (AIDS) infection (Ayele *et al.* 2004). WHO estimated that 70% (6 million)

of humans co-infected with TB and HIV live in Sub-Saharan Africa (Cosivi *et al.* 1998). In Uganda, official data of AIDS prevalence is 297.6/100,000 (73,657 cases out of the total national population of 24,748,977) at 31st December 2002 (Fountain Publishers 2005; Ministry of Health 2003). Although cases are rare, humans play a role in transmitting *M. bovis* to animals (Ayele *et al.* 2004). Grange and Yates reported that farm workers urinating in cowsheds may represent a source of infection for animals (Grange & Yates 1994).

Three main types of tubercle bacilli are recognised: *Mycobacterium tuberculosis*, *M. bovis* and *M. avium* complex (*M. avium-intracellulare-scrofulaceum*). *M. tuberculosis* and *M. bovis* are more closely related to each other than to the avian type (Aiello & Mays 1998), and are members of *M. tuberculosis* complex (MTC), which comprises *M. tuberculosis*, *M. africanum*, *M. bovis*, *M. microti* and *M. bovis* bacille Calmette-Guérin (BCG) as well as the newly characterised *M. canetti* and *M. caprae* comb (Ayele *et al.* 2004). The mycobacteria grouped in the MTC are characterised by 99.9% similarity at the nucleotide level and identical 16S rRNA sequences (Brosch 2002). *M. tuberculosis* rarely produces progressive disease in animals other than people and non-human primates and occasionally in dogs, pigs, and birds, while *M. bovis* can cause progressive disease in most warm-blooded vertebrates including humans. *M. avium avium* has a wide host range and is also pathogenic for pigs, cattle, sheep, deer, mink, dogs, cats and some cold-blooded animals (Aiello & Mays 1998).

In Africa, human TB is widely known to be caused by *M. tuberculosis*, however, an

unknown proportion of cases is due to *M. bovis* (Ayele *et al.* 2004). Tanzania is one of few developing countries with quantitative data on the prevalence of *M. bovis* in humans (Cleaveland *et al.* 2007). In the southern highlands region of Tanzania, *M. bovis* was isolated from 1/23 (4%) cases of pulmonary TB (Kazwala 1997), and from 6/21 (28.6%) cases of cervical adenitis (Kazwala 2001). In Arusha, 7 (10.8%) of 65 culture-positive cases of cervical adenitis was *M. bovis* (Mfinanga 2004).

4.1.4.3. *Taenia solium* cysticercosis

Porcine cysticercosis, caused by the zoonotic tapeworm *Taenia solium* is emerging as a serious agricultural problem and public health risk in Eastern and Southern Africa (Phiri *et al.* 2003). Humans are the only natural definitive host while pigs are the intermediate host. When humans ingest larvae (cysticerci) in raw or inadequately cooked pork, the larvae become tapeworms in their intestines (taeniosis). The infection to pigs occurs when they ingest eggs containing onchospheres of the adult tapeworm through ingesting human faeces. It is facilitated by their coprophagic habits (Sarti *et al.* 1992). As observed with pigs, humans also may become an intermediate host from ingestion of eggs of the adult tapeworm. In this case, cysticercosis develops in their tissue and organs (human cysticercosis). When the cysticerci lodge in the brain and spinal cord, the condition known as neurocysticercosis (NCC) arises. The clinical signs are headache, epileptic seizures, blindness, mental disturbance and even death (Phiri *et al.* 2003; White 2000).

Humans ingest the eggs through direct contact with another tapeworm carrier (e.g. food handlers), or indirectly with food (e.g. unwashed vegetables and fruits) or water contaminated with human faeces (Sarti *et al.* 1992). Therefore, those not eating pork

are at as much risk of contracting cysticercosis as those consuming pork (Heinz & MacNab 1965; Mafojane *et al.* 2003; Phiri *et al.* 2002). In South Africa, alarming information regarding an other mode of infection was reported; self-trained healers use *Taenia* segments and their pulverized contents in the treatment of severe intestinal tapeworm infections. Also, it is common for women to add *T. solium* segments to beer to punish their unfaithful husbands or lovers (Kriel 1997; Kriel & Joubert 1996; Mafojane *et al.* 2003).

Approximately 2.5 million people worldwide carry adult *T. solium*. Conservative figures mention 50,000 deaths every year due to NCC and no less than 20 million people infected with cysticerci of *T. solium* (Burneo & Garcia 2001). Cysticercosis is probably the single most common cause of acquired epilepsy in the developing world (Del Brutto *et al.* 2001). Globally, NCC is considered to be the most common parasitic disease of the nervous system (Burneo & Garcia 2001).   In Mexico, over 9% of all autopsies were positive for cysticercosis in a neurology hospital (Gonzalez *et al.* 1990). In Xoxocotla region, Mexico, 10.8% (167) of 1,552 persons who were thought to be infected with *T.solium* or cysticercosis were positive for cysticercosis antibodies using enzyme-linked immunoelectrotransfer blot assay (EITB) (Sarti *et al.* 1992). In Peru, 10-15% of neurology beds are devoted to the care of cysticercosis patients (Gonzalez *et al.* 1990). In South Africa, 30% of 70 epilepsy patients in Durban were diagnosed with cerebral cysticercosis by computed tomography (CT) scans and 12.9% of these patients had active cysts (Naidoo *et al.* 1987). In another study in South Africa, 50.9% of 106 epilepsy patients were diagnosed as cysticercosis at Rand Mutual Hospital and 18.5% of them had only active cerebral cysts (Campbell & Farrel 1987). In Zimbabwe, 11% of seizures patients with thigh

X-ray taken were found to have calcified cysticerci (Rachman 1970). In Mozambique, a survey at Maputo's Central Hospital found an enzyme-linked immunosorbent assay (ELISA) sero-positive rate of 12.1% (59 out of 489 epileptic patients) for cysticercosis (Mafojane *et al.* 2003; Vilhena *et al.* 1999). In Madagascar, 22.3-36.0% of adult epileptics (Mafojane *et al.* 2003; Michel *et al.* 1993) and 17.6% of epileptic children (Grill *et al.* 1996; Mafojane *et al.* 2003) were serologically positive for cysticercosis respectively. Infection might commonly occur at an early age as indicated by the cases seen at Groote Schuur Hospital, South Africa, where 51.5% of NCC patients were children (Mafojane *et al.* 2003; Thomson 1993). In northern Tanzania, using combination of cerebral CT scan, ELISA, western blot techniques, and cerebrospinal fluid (CSF) analysis, 22(10.4%) out of 212 people with epilepsy were diagnosed as probable NCC cases, and 7(3.3%) as cases of definite NCC. In total, 29(13.7%) cases were probable or definite NCC (Blocher 2007).

During the past decade, pig production has increased significantly in the East and South Africa (ESA) region (Phiri *et al.* 2003). Among ESA countries, Uganda showed the largest increase in pig population between 1980 and 2000, which was around five times. The pig population in Uganda was more than two times larger than any other ESA countries in 2000 (FAO 2002). In Uganda, pig traders often conduct pre-purchase lingual examination on pigs in the rural areas so that only lingual negative pigs are brought to the slaughterhouse (Phiri *et al.* 2003). However in Kampala, meat inspection is carried out only in the Wambizi abattoir (Kisakye & Masaba 2002). As described in Chapter 3, informal pig slaughter is a quite common practice in Kampala. The risk of taeniosis is very high and thus risk of cysticercosis is also high. Nevertheless, human cysticercosis has not been noted as a problem in

Uganda (Mafojane *et al.* 2003). In Kenya, Uganda, and Zambia, epidemiological survey of human cysticercosis has not been reported. Those countries lack resources such as computed axial tomography (CAT) scanners in working condition and also neurologists. Awareness of the disease is also poor. The research on NCC needs to be encouraged, as not a few people with epilepsy, mental problem and neurological disorder are assumed to be suffering from NCC in Uganda.

4.1.4.4. Gastrointestinal (GI) infections

Acute Gastrointestinal (GI) infections may be caused by a variety of agents, including bacteria, viruses, and protozoa (CDC 2004). Box 4.1 shows the most common causal pathogens of acute infectious diarrhoea (Park 1993) with zoonotic pathogens highlighted by asterisks. Some viruses and most of the bacterial and protozoal pathogens are zoonotic. Many pathogens under Genus coronavirus affect animals, but human corona virus is not zoonotic. Most of the agents under Genus Vibrio are zoonotic, but *V. cholerae*, the causal agent of cholera, and *V. cincinnatiensis* are not zoonotic according to the associated database of human pathogens by (Taylor *et al.* 2001) and International Classification of Diseases (WHO 2007). Acute infectious diarrhoea is acquired predominantly through oral ingestion of these pathogenic microorganisms and/or toxins produced by microorganisms. Sources include food and water contaminated with human or animal faeces, food contaminated with the pathogens, and self-inoculation with hands and fingers that have touched faecally contaminated objects (Powell 1991). On a clinical basis, infectious diarrhoea can be divided into two syndromes: 1) inflammatory, or bloody, diarrhoea and 2) non-inflammatory, or watery, non-bloody, diarrhoea. Inflammatory diarrhoea is caused by *Shigella*, *Salmonella*, amoebic colitis, *Campylobacter*,

Yersinia, invasive *Escherichia coli*, *Clostridium difficile*, while non-inflammatory diarrhoea is caused by viruses, *Vibrio*, *Giardia*, enterotoxigenic *E. coli* (ETEC), and enterotoxin-producing bacteria (Park 1993).

Diarrhoeal diseases in children are a major cause of morbidity and mortality. Many diarrhoeal pathogens such as rotavirus, *Salmonella*, *Campylobacter*, Aeromonas, enterohaemorrhagic *E. coli* (EHEC) and *Giardia*, have higher age-specific attack rates in children (Laney 1993).

Box 4.1 Causes of acute infectious diarrhoea. Data from Park (Park 1993) with zoonotic pathogens highlighted by asterisks. Zoonotic pathogens were defined by Taylor *et al.* (2001).

Viral	Bacterial	Protozoal
Rotavirus*	*Shigella**	*Gialdia lamblia**
Norwalk virus	*Salmonella**	*Entamoeba histolyca**
Norwalk-like agents	*Campylobacter**	*Cryptosporidium**
Enteric adenovirus	*Escherichia coli**	
Calicivirus*	*Yersinia**	
Astrovirus	*Clostridium difficile**	
Small round viruses	*Clostridium perfringens**	
Coronavirus	*Staphylococcus aureus**	
Herpes simplex virus	*Bacillus cereus**	
Cytomegalovirus	*Vibrio**	
	Chlamydia*	
	Treponema pallidum	
	Neisseria gonorrhoeae	

* Zoonotic pathogens.
  adapted by Makita, K.
  In June 2008

4.1.5. The health system in Uganda

The public sector health service is delivered through Health Sub Districts (HSD), which are the functional health zones smaller than the districts. In 2001, there were 56 districts and 214 HSDs (Nabyonga-Orem 2008). The health system is organised hierarchically, and managed at the national, regional, and HSD levels. The National referral hospitals provide comprehensive specialist services, and are involved in teaching and research. Regional referral hospitals provide general curative and preventive services, and specialist services. In HSD level, the HSDs are headed by HSD referral facility, which is a hospital or upgraded Health Centre IV (Nabyonga-Orem 2008). The Health Centres (HCs) in Uganda are graded on a system of II-IV (Banerjee 2005). A HC IV provides general preventive and curative services, emergency surgery and blood transfusion services. HC III and II, which are categorised lower level health units/facilities, provide mainly ambulatory services as included in the Uganda Minimum Health Care Package of Services (Nabyonga-Orem 2008).

4.1.6. User charges for health service in Uganda

In Uganda, the government abolished all forms of fees in all public health units on 1st March 2001, with hospitals allowed to operate a paying window for those who could afford to pay. However fees continue to be charged in Private for Profit and Private Not For Profit (predominantly church owned facilities) (Nabyonga-Orem 2008).

4.1.7. Health service units in urban and peri-urban areas of Kampala

There are two national referral hospital (Mulago and Butabika), 8 NGO hospitals, numerous small public clinics and health centres, 723 private/NGO clinics, an

international hospital and a military hospital in Kampala District (Fountain Publishers 2005). Also there are hospitals and clinics in Wakiso and Mukono Districts which were included in this study.

4.1.8. Medical recording system of Mulago National Referral Hospital

The medical recording systems of Mulago National Referral Hospital (Mulago Hospital), the largest national hospital in Uganda, were researched by the author, and are explained here to provide background.

In Mulago Hospital, the medical records are kept in three systems; outpatient records, inpatient records and casualty records. Outpatients are registered at the main reception and are given a registration number. The name, sex, age, address (up to LC2: Local Council, parish level) and registration number of outpatients are recorded in the registration book. Male, female, and paediatric patients are registered in separate registration books. Physicians record the name, registration number and diagnosis of patients on the diagnosis assessment form after a clinical examination. Details of the examination and treatment for each patient are recorded in the individual clinical record. All of the data are stored in the Medical Record Division in the hospital in paper form. The sex, age category (under/ over 5 years old), diagnosis and month of diagnosis are extracted from the diagnosis assessment form, and entered in the digitised electronic database. The database is used for the monthly reports to the Ministry of Health.

Admitted patients (inpatients) are registered in the separate recording system. Inpatients are given an inpatient registration number distinct from the outpatient

numbering system. Individual information includes name, sex, age, address up to LC1 (village) level, date of admission, International Classification of Diseases and Related Health Problems (ICD) disease code (WHO 2007) and details of clinical examinations and treatments; all are recorded in the individual medical record, and stored in the medical records store. The list of the individual records; inpatient registration number, sex, age, date of admission and ICD code of inpatients are kept as monthly inpatient registration cards in the Medical Record Division Office.

The casualty department has its own registration book. Dog bites or road accidents are examples of the cases recorded in this system. The sex, age category (under/ over 5 years old), diagnosis, and month of diagnosis are recorded in the outpatient electronic database.

4.2. Materials and methods

4.2.1. Selection of the health service unit

4.2.1.1. Study site

Interviews to LC1 (Local Council I) leaders were conducted to select the most appropriate health service unit in order to identify the most common zoonoses affecting urban and peri-urban human populations in 73 LC1s in and around Kampala, the capital city of Uganda (Fig 3.1, Section 3.2.1). The selection of LC1s was described in the Chapter 2, section 2.2.2 and Chapter 3, section 3.2.1. The 75 LC1s selected were classified into 48 urban, 11 peri-urban and 16 rural LC1s (Fig 3.2), and their development types were determined by the author (Fig 3.3, Table 3.2). However no adults were found in an urban LC1 during day time (described in Chapter 3) and there was a refusal from another urban LC1 because the LC1 Chairman and the other participants were not sure about health service seeking behaviour of the LC1 residents. Therefore the number of LC1s analysed in the present study became 73.

4.2.1.2. Collection of the information

Information regarding the health service was collected during the Village Characteristic Survey (VCS; detailed in Chapter 2). LC1 leaders were interviewed using a questionnaire in 75 LC1s (48 urban, 11 peri-urban and 16 rural LC1s). Box 4.2 shows the contents of the questionnaire (for details see Appendix I). The number of health service units in each LC1 was asked to describe the distribution of these units within the Kampala economic zone. Health service units which people usually use were asked to describe their access to the medical service for non-severe illness. The units which people use when they have enough money were asked to describe

the difference of health service seeking trends between wealthier and non-wealthier people. The units to which people go when they are seriously ill were asked to describe the best facilitated and affordable hospital in the Kampala economic zone.

Box 4.2 Contents of the questionnaire regarding to health service

1. Numbers of health service facilities in your LC1

·Numbers of National hospitals, District hospitals, mission hospitals, Islamic hospitals, health centres, private dispensaries, NGO dispensaries, private clinics, NGO clinics, and private pharmacies

2. Best health service facilities in Kampala economic zone

·Names of health service facilities people usually go when they are sick

·Names of health service facilities people go to if they have enough money

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4.2.1.3. Selection of the health service units

The answers to the interviews at 75 LC1s were entered into a Microsoft Excel spreadsheet (Microsoft Office XP, Redmond, USA). Data were divided into each development type of urban LC1s, and peri-urban and rural LC1s, then analysed. The proportion of LC1s using each health service unit and its confidence interval were calculated using Chi-square test with statistical software R 2.4.1. Results from this analysis were combined and a diagram of people's access to health service was constructed (section 4.3.1).

4.2.2. **Medical Record Survey**

4.2.2.1. Research clearance

The research project, 'Urban and peri-urban livestock farming in Uganda: Role in food security and poverty alleviation versus risks of zoonotic diseases', including the methodologies in this Chapter, was approved by the Uganda National Council for Science and Technology (UNCST) on 14th September 2005, with its reference number A 432. The ethicality of this project was also assessed and approved. Access to medical records of Mulago National Referral Hospital, Butabika Referral Hospital, District Health Services, Entebbe Hospital, Nsambya Hospital was granted by the Director General Health Services, Ministry of Health, Uganda on 21st November 2005, (reference number ADM/130/313/05). The medical records of only Mulago National Referral Hospital were accessed throughout the study because only this single hospital had an access from all of the 75 LC1s studied in and around Kampala.

4.2.2.2. Identification of the most important zoonotic diseases affecting urban and peri-urban populations in Kampala

Monthly summaries of the digitised diagnosis record database of Mulago Hospital from March 2005 to February 2006 were obtained at the Medical Record Division. Monthly summaries were manually entered into a Microsoft Excel spreadsheet and analysed for identification of the most significant zoonotic diseases affecting urban and peri-urban populations in Kampala.

Total numbers of cases for each diagnosis of the twelve months were calculated in the Excel spreadsheet. Each diagnosis was judged whether zoonotic pathogen(s) can cause it or not, and the causal pathogen(s) were researched using the list of 838

zoonotic pathogens in the Appendix by Taylor *et al*. (2001) and associate database, and International Classification of Diseases (WHO 2007). Published papers, books and the other internet sources were researched to support these judgements. Vague diagnoses such as fever, cough and pneumonia were excluded from the judgement. Diarrhoea, dysentery, enteritis, and gastroenteritis (Park 1993) were combined and named as GI infections. Epilepsy, neurological disorders, seizure, spasm, fits, mental and psychiatric problems were combined and named as neurological disorder assuming possible involvement of neurocysticercosis (White 2000). Brucellosis, orchitis (Chin 2000), joint pain (Mutanda 1998) and back pain (Galukande *et al*. 2005) were combined as brucellosis. Tuberculosis and back pain (Galukande *et al*. 2005) were combined as tuberculosis. Bilharzia and schistosomiasis(East African Literature Bureau. 1974)   were combined as schistosomiasis. After the judgement of all diagnoses, the most common potential zoonotic diagnoses and their possible zoonotic causal pathogens in Mulago Hospital were identified.

4.2.2.3. Selection of the diseases which represent identified zoonotic diseases

Identification of the most important zoonotic diseases in urban and peri-urban areas of Kampala (*Mycobacterium bovis* tuberculosis, brucellosis, cysticercosis, and GI infections; selection of the diseases will be described in the results section) lead necessity of investigating these diseases further to describe their characteristics. For the purpose, information of individual patients such as age and sex was necessary to investigate from individual medical records. However, since *M. bovis* tuberculosis and cysticercosis were not determined based on the biological identification, representative diseases needed to be selected for these zoonotic diseases.

Abdominal tuberculosis was selected to study bovine tuberculosis because it might be predominantly caused by *M. bovis*. Globally, 9.4% of extra-pulmonary TB is estimated to be due to *M. bovis* (Cosivi *et al.* 1998). Since contaminated milk is the usual source of infection with *M. bovis* amongst town dwellers (Collins & Grange 1987), even larger proportion of abdominal TB may be caused by the agent. In fact, high proportion of abdominal TB due to *M. bovis* (80%, 20% was due to *M. tuberculosis* out of 15 cultures) was reported in USA (Veeragandham 1996).

Epilepsy was selected to study neurocysticercosis (NCC) because epilepsy was known to be caused by NCC. However, the percentage of epilepsy due to NCC has a variety in Sub-Saharan Africa; using CT scan, 30% of 70 patients with epilepsy (PWE) and 50.9% of 106 PWE (Campbell & Farrel 1987) in South Africa were due to NCC. In northern Tanzania, using combination of cerebral CT scan, ELISA, western blot techniques, and cerebrospinal fluid (CSF) analysis, 22(10.4%) out of 212 PWE were diagnosed as cases of probable NCC, and 7(3.3%) as cases of definite NCC. In total, 29(13.7%) cases were probable or definite NCC (Blocher 2007).

4.2.2.4. Tracing back to the individual records

To study the selected diseases in more details, individual information on sex, age, month of attendance and LC2s (parishes) where patients came from were collected from hard paper copy. The digitised medical record database in Mulago hospital did not include this individual information.

The information of age, sex, LC2, and month of attendance was collected from three different sources; Tuberculosis Ward inpatient records, serological test result record

book in the Department of Microbiology, and outpatient assessment forms in the Department of Medical Records in Mulago Hospital. For abdominal tuberculosis, inpatient medical records of the patients admitted to the Tuberculosis Ward during 2005 were investigated. The records already had the date of attendance, age, sex, and LC2 where patients were from. For brucellosis, serological test result record books were investigated for brucella agglutination test (BAT) results tested from June 2004 to May 2006 in the Department of Microbiology in Mulago Hospital. However, serological test result record books lacked information on the LC2s where patients came from. Therefore, outpatient registration books were collated with registration number and patient's name which were also recorded in the serological test result books, and the accurate date of attendance, age, sex and LC2s where patients came from were obtained. For epilepsy, outpatient diagnosis assessment forms from June 2004 to May 2006 were investigated for the date of attendance and the registration numbers. The outpatient registration books were then collated with the registration number and patients' name for accurate date of attendance, sex, age, and LC2s where patients were from. For GI infections patients, outpatient diagnosis assessment forms in 2005 were investigated for the date of attendance and the registration numbers. The outpatient registration books were then collated with the registration number and patients' name for accurate date of attendance, sex, age, and LC2 where patients were from. The LC2 (parishes) where patients were from will be analysed and described in Chapter 5.

4.2.3. Disease summaries of the studied diseases

4.2.3.1. Effects of age and sex against incidents of the studied diseases

The effects of age and sex on incidents of abdominal tuberculosis, brucellosis, epilepsy and GI infections were analysed using individual records.

Proportions of male and female patients for each disease were analysed using Chi-square test in statistical software R.2.4.1.

Mean age was compared between male and female patients using one-way ANOVA in R 2.4.1. Before being tested using the one-way ANOVA, data were transformed using the boxcox transformation (Box 1964) to correct the skew of the error structure into normal distribution. Obtained means of age in male and female patients were then back-transformed to the original scale.

4.2.3.2. Seasonality of incidents in the studied diseases

The figures showing seasonality of the incidents were constructed using Microsoft Excel, and observed findings were described.

4.2.4. Limitations

There were three limitations to this study; firstly, low traceability of individual patient records; secondly, diagnoses do not necessarily specify the causal pathogens. Thirdly, records from only one hospital were studied.

Low traceability was intrinsic to the medical recording system. The Medical Record Division of the Mulago Hospital started the digitised medical recording system using Microsoft Access for both outpatient and inpatient records in 2005. However unfortunately, registration numbers of the patients were not entered in the database. Thus the database did not have any traceability of individual patients. Also in the paper form, physicians sometimes did not record the registration numbers of outpatients, and in many cases, the hand writing of the physicians was indecipherable.

It is common that causal pathogens are not identified in clinics in any part of the world, and a clinical record survey may not show the information on pathogens. However, such clinical diagnosis records may provide some useful evidence of particular diseases.

Mulago Hospital was accessed from all of 73 LC1s according to the interviews, and the hospital was most appropriate for this study of zoonotic diseases in and around Kampala. However, ideally several health service units such as Missionary hospitals and Health Centres IV could have been studied if budgets and time had allowed.

4.3. Results

4.3.1. Selection of the health service units for the study

4.3.1.1. LC1s having health service units in and around Kampala

Table 4.1 shows numbers and percentages of LC1s with health service units in the studied 73 LC1s in and around Kampala. The most common health service units were private clinics; 43 out of 73 LC1s (58.9%, 95%CI (47-70)) had the units. Private clinics were seen in all the city centre and slum LC1s, and in 71% (12/17) of trading centre LC1s. About half of high income residential (50%, 1/2), middle income residential (55%, 11/20) and peri-urban LC1s (55%, 6/11) had private clinics, and even 38% of rural LC1s (6/16) had them. Next most common units were private pharmacies; 22 LC1s (30.1%, 95%CI (20-42)). Four LC1s had Health Centres II, 2 LC1s had Health Centres III, 3 LC1s had NGO clinics. One LC1 each had a private, a Missionary and an Islamic hospital. Overall, 74% of LC1s (54/73) had at least one health service unit. In urban areas, 7 middle income residential LC1s (35%, 7/20) and 2 trading centre LC1s (12%, 2/17) did not have any type of health service unit but there were units near the LC1s within 10 minutes walking distance for healthy people. In peri-urban areas, 82% of LC1s (9/11) had at least one unit, and one LC1 without a unit had Health Centre II within 800 m from the centre of the LC1. The respondents in another peri-urban LC1 did not specify the time or distance to their nearest unit. In rural areas, 50% of the LC1s (8/16) did not have any type of health service unit: their nearest unit was sometimes far (1 mile or 2 miles), however according to all of the respondents in the LC1s without any unit, each rural LC1 has a village drug distributor assigned by the Local Council who provides drugs as first aid.

Table. 4.1 Numbers and percentages of LC1s having health service units in the studied 73 LC1s in and around Kampala

Develop. type (No. of LC1s)	Any units	Private hospital	Mission hospital	Islamic hospital	Health Centre II	Health Centre III	Private dispensary	Private clinic	NGO clinic	Private pharmacy
City centre	1	0	0	0	0	0	0	1	0	1
(n=1)	100(6-)	0(0-94)	0(0-94)	0(0-94)	0(0-94)	0(0-94)	0(0-94)	100(6-)	0(0-94)	100(6-)
High income	2	0	1	0	0	0	0	1	0	0
(n=2)	100(20-)	0(0-80)	50(10-91)	0(0-80)	0(0-80)	0(0-80)	0(0-80)	50(10-91)	0(0-80)	0(0-80)
Middle income (n=20)	13	0	0	0	1	0	0	11	0	2
	65(41-84)	0(0-20)	0(0-20)	0(0-20)	0.5(0.3-27)	0(0-20)	0(0-20)	55(32-76)	0(0-20)	10(2-33)
Slum (n=6)	6	0	0	0	0	0	0	6	1	2
	100(52-)	0(0-48)	0(0-48)	0(0-48)	0(0-48)	0(0-48)	0(0-48)	100(52-)	17(1-64)	33(6-76)
Trading centre	15	1	0	1	1	0	1	12	2	9
(n=17)	88(62-98)	6(0.3-31)	0(0-23)	6(0.3-31)	6(0.3-31)	0(0-23)	6(0.3-31)	71(44-89)	12(2-38)	53(29-76)
Peri-urban	9	0	0	0	0	2	0	6	0	6
(n=11)	82(48-97)	0(0-32)	0(0-32)	0(0-32)	0(0-32)	18(3-52)	0(0-32)	55(25-82)	0(0-32)	55(25-82)
Rural	8	0	0	0	2	0	0	6	0	2
(n=16)	50(28-72)	0(0-24)	0(0-24)	0(0-24)	13(2-40)	0(0-24)	0(0-24)	38(16-64)	0(0-24)	13(2-40)
Total	54	1	1	1	4	2	1	43	3	22
(n=73)	74(62-83)	1(0.1-8)	1(0.1-8)	1(0.1-8)	5(2-14)	3(0.5-10)	1(0.1-8)	59(47-70)	4(1-12)	30(20-42)

The number in top of each cell is the number of LC1s. The numbers in bottom of each cell are the percentage (%) and its 95% confidence interval.

High income: high income residential area. Middle income: middle income residential area

4.3.1.2. Commonly used health service units

Table 4.2 shows the health service units that people in the studied 73 LC1s usually use when they are sick (multiple choices were allowed). People used private clinics and pharmacies for first aid and non-serious illness, but they also used Mulago Hospital, Missionary hospitals and Health Centres. Other than private clinics, Mulago Hospital was the most popular health service unit (55%, 40/73). Compared with Missionary hospitals and Health Centres, Mulago Hospital received patients from all income groups and all urbanicity groups. Low income groups (living in slum areas) did not use Missionary hospitals. Health Centres might be used well in rural areas, but there was no access from high income residential LC1s.

Table. 4.2 Use of health service units in 73 LC1s

Development type/ urbanicity	No. of LC1s	Mulago Hospital	Missionary hospitals	Health Centres
City centre	1	1	0	0
Percentage (%)		100(6-100)	0 (0-94)	0 (0-94)
High income	2	1	1	0
Percentage (%)		50 (10-91)	50 (10-91)	0 (0-80)
Middle income	20	13	8	6
Percentage (%)		65 (41-84)	40 (20-64)	30 (13-54)
Slum	6	5	0	2
Percentage (%)		83(36-99)	0 (0-48)	33(6-76)
Trading centre	17	7	6	4
Percentage (%)		41(19-67)	35(15-61)	24(8-50)
Peri-urban	11	7	4	3
Percentage (%)		64(32-88)	36(12-68)	27(7-61)
Rural	16	6	3	8
Percentage (%)		38(16-64)	19 (5-46)	50(28-72)
Total	73	40	22	23
		55(43-66)	30(20-42)	32(21-44)

The number in top of each cell is number of LC1s. The numbers in the bottom of each cell are the percentage (%) and its 95% confidence interval.

4.3.1.3. Health service units of highest standard

Table 4.3 shows the health service units that people use when they can afford any treatment at any unit. The question was asked to determine the health service units with the highest standards in and around Kampala. Most of the respondents answered with the name of more than one health service unit. This question was not asked in slum areas to avoid upsetting respondents' feelings. The most popular choice was Missionary hospitals (63%, 42/67) and a significantly large proportion of LC1s preferred Mulago Hospital (43%, 29/67, x^2=4.31, df=1, p=0.038). The standard of the health service in Mulago Hospital was thought to be high by respondents as it occupied the second position even in this question. Mulago Hospital offers free service, but people still use it even when they can afford to go to any expensive hospital.

Three LC1s located south of Kampala city centre replied that they use Entebbe Hospital. The LC1s were still far from Entebbe but the influence of Entebbe city was observed.

Table. 4.3 Health service units that people in the studied 73 LC1s use when they can afford any treatment at any unit

Development type/ urbanicity	No. of LC1s	Mulago Hospital	Missionary hospitals	Private hospitals	Entebbe hospital
City centre	1	0	1	0	0
Percentage		0 (0-94)	100(6-100)	0 (0-94)	0 (0-94)
High income	2	0	2	0	0
Percentage		0 (0-80)	100(20-100)	0 (0-80)	0 (0-80)
Middle income	20	14	11	8	2
Percentage		70(46-87)	55(32-76)	40 (20-64)	10(2-33)
Trading centre	17	4	10	7	0
Percentage		24(8-50)	59(33-81)	41(19-67)	0(0-23)
Peri-urban	11	7	6	4	0
Percentage		64(32-88)	55(25-82)	36(12-68)	0(0-32)
Rural	16	4	12	5	1
Percentage		25(8-53)	75(47-92)	31(12-59)	6(0.3-32)
Total	67	29	42	24	3
		43(31-56)	63(50-74)	36(25-49)	4(1-13)

The number in top of each cell is number of LC1s. The numbers in the bottom of each cell are the percentage (%) and its 95% confidence interval

4.3.1.4. Health service units people use when they are seriously ill

Table 4.4 shows the health service units which people in the studied 73 LC1s use when they are seriously ill. Ninety percent (66/73) of the studied LC1s answered that they use Mulago Hospital. The percentage of LC1s using Mulago Hospital (90%) was significantly larger than that of Missionary (15%, 11/73, x^2=80.1, df=1, p<0.001), private (5%, 4/73, x^2=102.1, df=1, p<0.001), and Entebbe (3%, 2/73, x^2=105.6, df=1, p<0.001) hospitals. LC1s of all development types and levels of urbanicity had access to the Mulago Hospital.

Table. 4.4 Health service units which people in the studied 73 LC1s use when they are seriously ill. The number in top of each cell is number of LC1s

Development type/ urbanicity	No. of LC1s	Mulago Hospital	Missionary hospitals	Private hospitals	Entebbe Hospital
City centre	1	1	0	0	0
Percentage (%)		100(6-100)	0 (0-94)	0 (0-94)	0 (0-94)
High income	2	2	0	0	0
Percentage (%)		100(20-100)	0 (0-80)	0 (0-80)	0 (0-80)
Middle income	20	18	2	0	1
Percentage (%)		90(67-98)	10(2-33)	0(0-20)	0.5(0.3-27)
Slum	6	6	0	0	0
Percentage (%)		100(52-100)	0 (0-48)	0 (0-48)	0 (0-48)
Trading centre	17	15	5	2	0
Percentage (%)		88(62-98)	29(11-56)	12(2-38)	0 (0-23)
Peri-urban	11	10	1	0	0
Percentage (%)		91(57-99.5)	9(0.5-43)	0(0-32)	0 (0-32)
Rural	16	14	3	2	1
Percentage (%)		88(60-98)	19 (5-46)	13(2-40)	6(0.3-32)
Total	73	66	11	4	2
		90(81-96)	15 (8-26)	5 (2-14)	3(0.5-10)

The numbers in the bottom of each cell are the percentage (%) and its 95% confidence interval

4.3.1.5. Selection of the health service unit to study

To select the health service units to study zoonotic diseases affecting urban and peri-urban areas of Kampala economic zone, the trends in people's health service seeking were combined in Fig 4.1. Fig 4.1 shows the access to the health service units from LC1s in different levels of urbanicity and development types. In the figure, high income and middle income residential LC1s were combined as residential, because of the small number of high income residential LC1s (n=2). Regardless of the level of urbanicity, Entebbe, the city 34km south from Kampala, had a strong influence, and LC1s in Ssisa and Makindye Sub-counties of Wakiso District had access to Kisubi and Entebbe Hospital. Therefore, another group termed 'near Entebbe' was shown in Fig 4.1 and Fig 4.2.

The figure showed the concentration of the people's access on Mulago Hospital. As explained already in the previous sections, LC1s of all developing types and levels of urbanicity were using the hospital. All of the respondents in the studied 73 LC1s mentioned Mulago hospital in at least one of the questions; health service units which 1) people usually use, 2) people use when they are afford to any treatment, and 3) people use when they are seriously ill. Moreover, all respondents in the LC1s that use Missionary hospitals and Entebbe hospital when people are seriously ill said that even these hospitals refer patients to Mulago Hospital. Therefore, Mulago Hospital was considered the most appropriate for the present research.
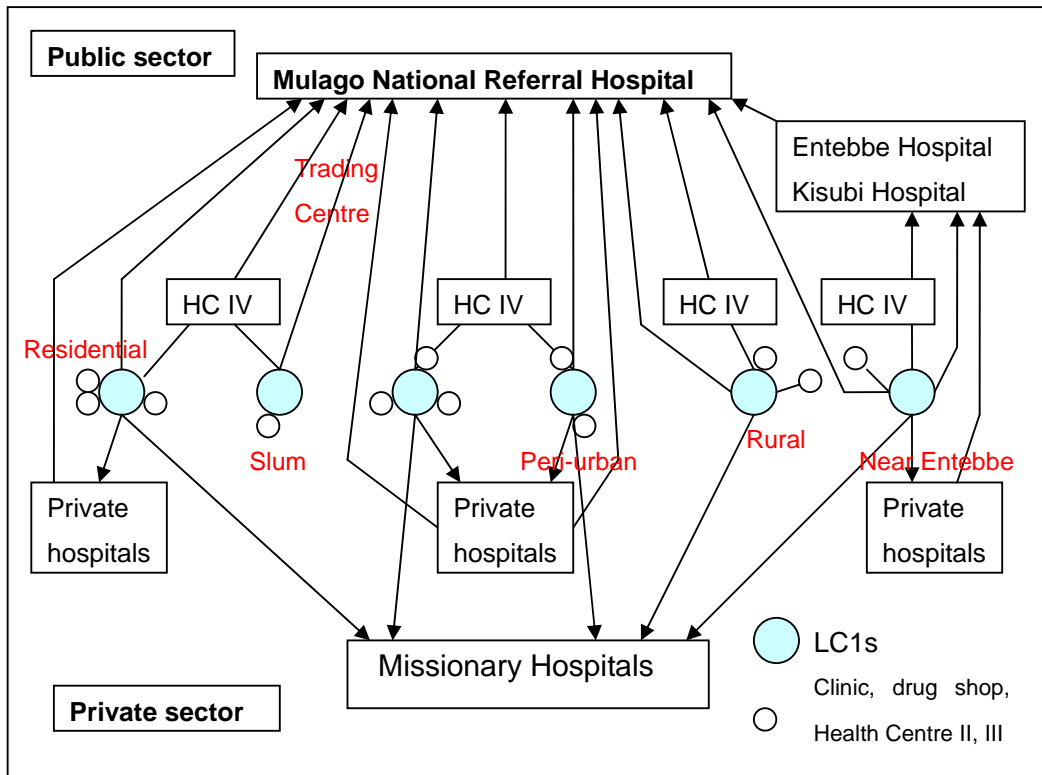
Fig. 4.1 Access to the health service units from LC1s in different levels of urbanicity and development types
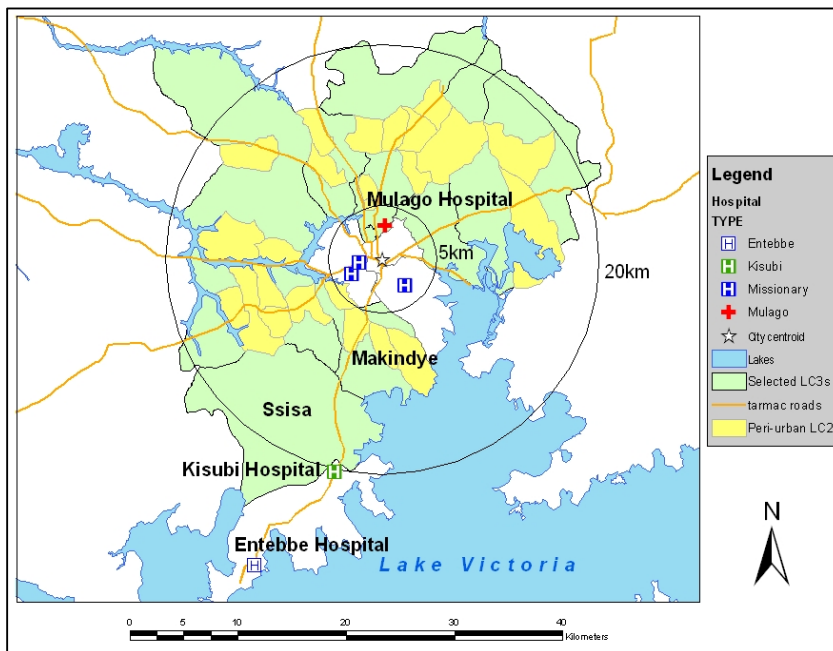
Fig. 4.2 Map showing hospitals in and around Kampala. Mulago Hospital, Kisubi Hospital, and Entebbe Hospital are shown. Missionary hospitals shown in blue are Lubaga, Namirembe and Nsambya.

4.3.2. Identification of the most important zoonotic diseases in and around Kampala

During a year between March 2005 and February 2006, 62,671 outpatients were diagnosed under 554 different diagnoses. Table 4.5 shows the top most common 15 diagnoses in the medical record summary.

Table. 4.5 Top 15 most common diagnoses in the medical record summary between March 2005 and February 2006 in Mulago Hospital

Rank	Diagnoses	Number of cases
1	Malaria	17,951
2	Reproductive tract infections (RTI)	5,622
3	Pneumonia	2,927
4	No diagnosis	2,270
5	Urinary tract infection (UTI)	2,211
6	Skin	2,184
7	Gastroenteritis	1,560
8	Pain	1,263
9	Pelvic inflammatory disease (PID)	1,226
10	Peptic ulcer disease (PUD)	992
11	Coryza	972
12	Cough	807
13	Tuberculosis	797
14	Candidiasis	597
15	Helminthiasis	543
	Others	20,749

The majority of the common diagnoses were infectious diseases. Malaria was the most common diagnosis (17,951) among 554 diagnoses. The diagnoses included symptoms such as pain and cough, and they were not necessarily the definitive diagnoses.

All 554 diagnoses were classified as either possibly zoonotic or not to present the liberal upper limit of the number of zoonotic diseases. Respiratory diseases such as flu, cough and cold were not selected as possible zoonoses because there would be too many causative pathogens and although many of them could have been zoonotic, there was no indication of this in the information available. Vague diagnoses such as infection and abscess were excluded from the list of the diseases. As a result, 19 diagnoses possibly caused by zoonotic pathogens were selected, and they accounted for 6,770 (10.8%) out of 62,671 outpatients (Table 4.6).

In Table 4.6, diagnosis 'GI infection' was made combining gastroenteritis, enteritis, gastritis, diarrhoea, and dysentery. 'Brucellosis' was made combining brucellosis (187 cases), BAT (63), orchitis (41), epididymitis (1), scrotal swelling (1), backache (257), and spondylosis (94). Backache was included with brucellosis because Galukande *et al.* (Galukande *et al.* 2005) reported that 17.2% out of 204 orthopedic clinic patients whose chief complaint was low back pain at Mulago Hospital had serious pathology due to tuberculosis, brucellosis, fractures and degenerative changes. Spondylosis causes osteophyte formation on the vertebral foramina and may also be caused by brucellosis (Kyebambe 2005). Backache and spondylosis could be thus added to tuberculosis, but they were not.

Table. 4.6 Potential zoonotic diagnoses and their possible zoonotic cause with their liberal upper limit of the numbers of cases in the medical record summary of Mulago Hospital (March 2005 to February 2006)

Rank	Diagnoses	Possible zoonotic cause	Cases
1	GI infection	Viruses, bacteria, and protozoa	3,525
2	Tuberculosis	*Mycobacterium bovis*	797
3	Brucellosis	*Brucella abortus, B. melitensis, B. suis, B. canis*	644
4	Epilepsy, neurological problem	*Taenia solium* (neurocysticercosis)	613
5	Candidiasis	*Candida albicans, C.glabrata, C.guilliermondii, C.krusei,C.lusitaniae,C.parapsilosis, C.tropicalis*	597
6	Tinea (ring worm)	Many fungus	210
7	Cellulitis	*Staphylococcus, Streptococcus*	132
8	Scabies	*Sarcoptes scabiei*	99
9	Typhoid fever	*Salmonella enterica* serovar Typhi	38
10	Fungal infection	Many fungi	32
11	Animal bite	Rabies virus	25
12	Hepatitis	Hepatitis E virus	20
13	Tinea capitis	*Microsporum canis,Tricophyton verrucosum*	20
14	Elephantiasis	*Wuchereria bancrofti, Brugia malayi*	10
15	Tetanus	*Clostridium tetanus*	4
16	Shistosomiasis	*Schistosoma*	3
17	Encephalitis	Encephalitis viruses	1
18	Hook worm	*Necator americanus*	1
19	Trichuriasis	*Trichuris trichiura, T. vulpis, T. suis*	1

The diagnoses possibly linked to neurocycticercosis (NCC) were neurological problems (268), epilepsy (135), neuritis (95), spasm (45), mental problem (30), psychiatric problem (14), fits (14), neuropathy (8), and seizures (2 cases). These diagnoses other than epilepsy were combined and classified as neurological problem in Table 4.6. Animal bites including 18 dog bites were possibly caused by rabies. Of course, there was no evidence that these diagnoses were caused by zoonotic pathogens because the details of diagnostic tests were not recorded in the digitised diagnosis records.

In Tanzania, 1/23 (4%) cases of pulmonary TB (Kazwala 1997), 6/21 (28.6%) cases of cervical adenitis (Kazwala 2001), and 7 (10.8%) of 65 culture-positive cases of cervical adenitis were due to *M. bovis* (Mfinanga 2004), i.e. roughly 4% to 28.6% of 797 TB cases (32-228) were estimated to be due to *M. bovis*.

In South Africa, the percentages of patients with epilepsy (PWE) due to NCC were 30% of 70 PWE and 50.9% of 106 PWE (Campbell & Farrel 1987) using CT scan. In northern Tanzania, using a combination of cerebral CT scan, ELISA, western blot techniques, and cerebrospinal fluid (CSF) analysis, 22(10.4%) out of 212 PWE were diagnosed as cases of probable NCC, and 7(3.3%) as cases of definite NCC. In total, 29(13.7%) cases were probable or definite NCC (Blocher 2007). Therefore, roughly 13.7% to 50.9% of 613 epilepsy and neurological problem patients (84-312) were estimated to be due to *T. solium* NCC.

Many brucellosis cases were already diagnosed serologically at Mulago Hospital. We conclude that the most important zoonotic diseases in and around Kampala were

identified as bovine tuberculosis, brucellosis, neurocysticercosis, GI infections and fungal infections including candidiasis, tinea, and tinea capitis.

4.3.3. Summaries of the most important zoonotic diseases traced in and around Kampala

4.3.3.1. Abdominal tuberculosis

In 2005, 86 patients were admitted in Tuberculosis Wards in Mulago hospital. Number of male patients was 41 and female was 45. The proportions of male (0.477) and female (0.523) were not significantly different (x^2=0.21, df=1, p=0.647).
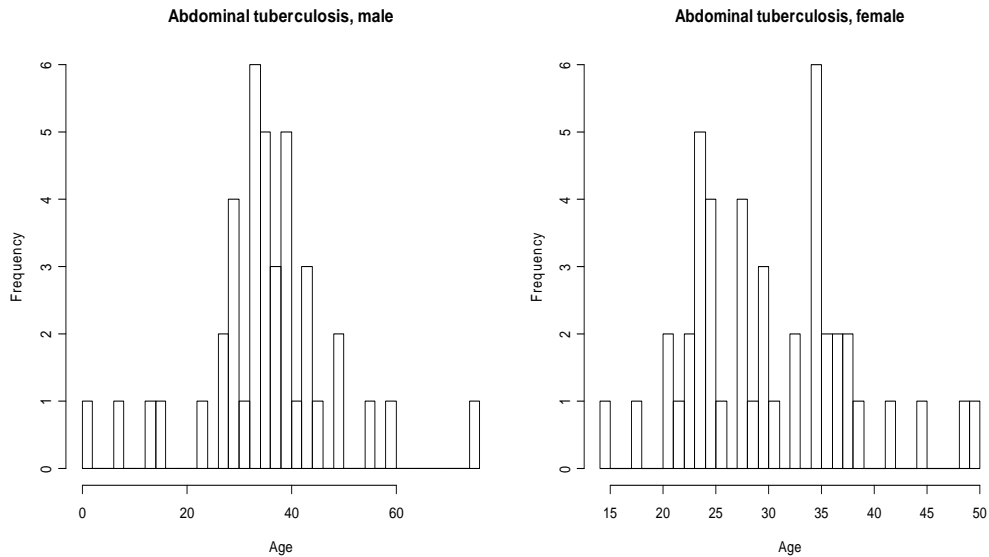
Fig. 4.3 Age distributions of male and female abdominal tuberculosis patients

Female patients (mean=30.5) were significantly younger than male patients (mean=35.7, p=0.026, Fig 4.3).

4.3.3.2. Brucellosis

From June 2004 to May 2006, 652 patients were positive for the brucella agglutination test (BAT). Out of 652 patients, 337 outpatients were traced for age, sex and address. The other patients could not be traced because either registration numbers were not written in the serological test results book, or the numbers were not consistent with the numbers in the outpatient registration book. Moreover, there was an inconsistency between number of brucellosis outpatients in the diagnosis record summary and number of BAT positive patients in the serological test result book. This was due to the failure of many patients to return test results to the physician (personal communication by the medical staff in Department of Microbiology, Mulago hospital).

Number of traced male patients was 104 and female was 233. The proportion of females (0.691) was significantly larger than males (0.309, x^2=97.2, df=1, $p<0.001$).

Mulago Hospital receives significantly more female outpatients than males in total, not only brucellosis patients. In the diagnosis record summary from October 2005 to February 2006, among a total of outpatients 23,294, female patients (13,982, 60.0%) were significantly more than male patients (9,312, 40.0%, x^2=1871.7, df=1, $p<0.001$). However, the proportion of brucellosis female patients was significantly greater than the total proportion of female patients (x^2=11.5, df=1, $p=0.001$); being female was a significant risk factor for brucellosis.

Female patients (mean=32.9) were significantly older than male patients (mean=27.5, $p<0.001$, Fig 4.4).
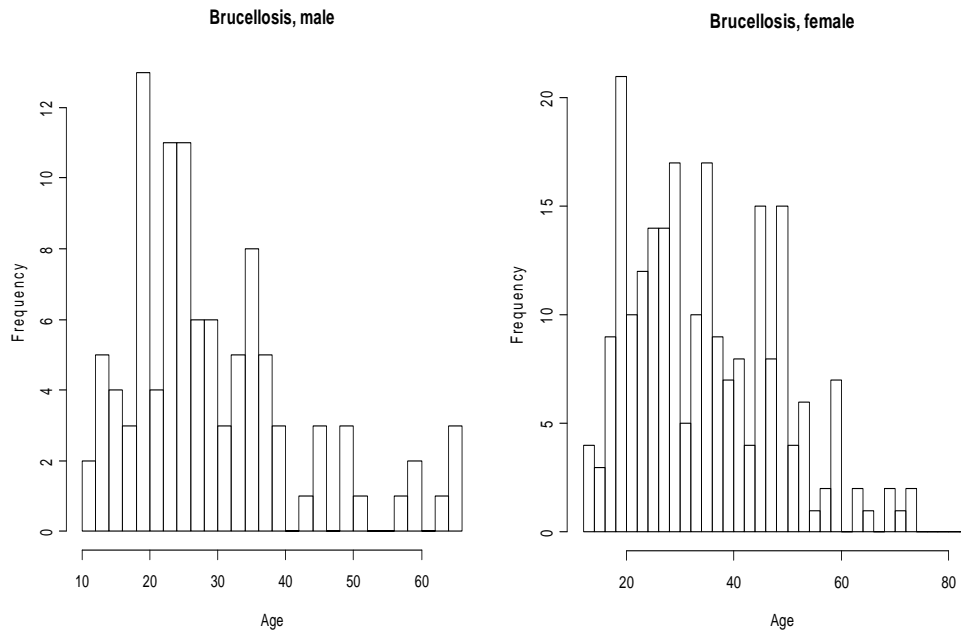
Fig. 4.4 Age distributions of male and female brucellosis patients

4.3.3.3. Epilepsy

From June 2004 to May 2006, the details of 95 epilepsy outpatients were traced back in Mulago Hospital; 61 were male and 34 were female. The proportion of male patients (0.642) was significantly larger than female (0.358, x^2=14.2, df=1, p<0.001).

Mean age of male patients (7.5) was not significantly different from female patients (10.0, p=0.026, Fig 4.5). Both male and female histogram showed bimodal pattern, and the first very large mode was seen in very young ages in both sexes.
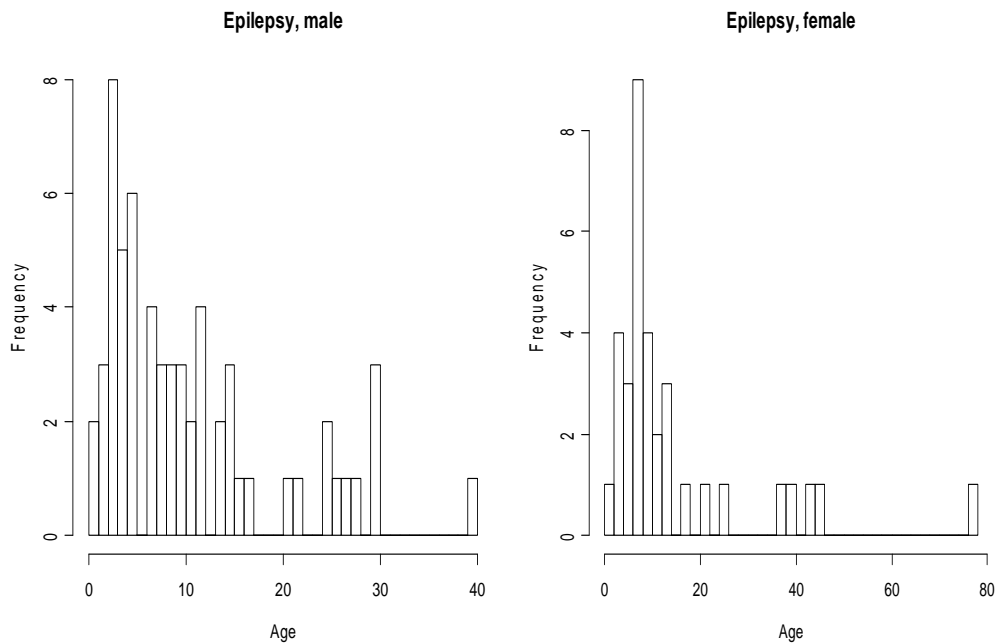
Fig. 4.5 Age distributions of male and female epilepsy patients

4.3.3.4. GI infections

In 2005, details of 250 GI infections outpatients were traced back in Mulago Hospital; 120 were male and 130 were female. The proportion of male patients (0.520) was not significantly different from female patients (0.480, x^2=0.65, df=1, p=0.421).

Mean age of male patients (1.7) was not significantly different from female patients (2.1, p=0.271, Fig 4.6).
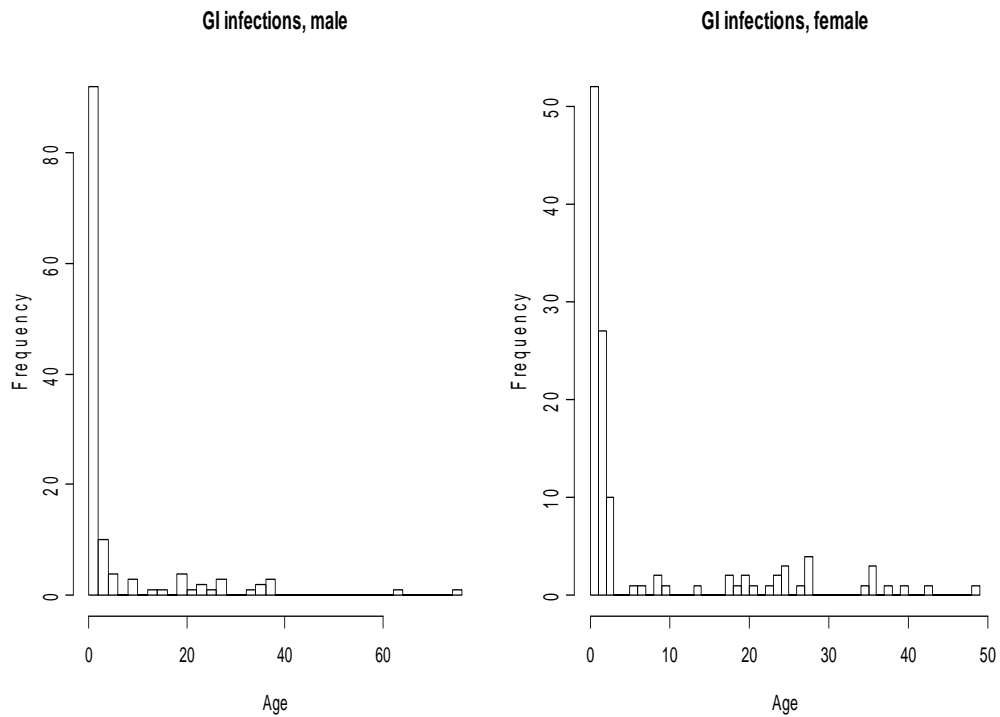
Fig. 4.6 Age distributions of male and female GI infections patients

4.3.3.5. Seasonality of the most significant zoonotic diseases in and around Kampala

Fig 4.7, 4.8, 4.9 and 4.10 shows four different seasonal patterns for abdominal tuberculosis, brucellosis, epilepsy, and GI infections respectively (note: brucellosis and epilepsy were shown in 2 years scale started in June 2004).

In Uganda, a bimodal rainfall pattern is seen with two dry seasons; one at mid-year (around June) which is short and uncertain, and one at the end of the year (around December-January), which is longer and more pronounced (Manning 1956).

The seasonality related to rainfall was not observed in abdominal tuberculosis and epilepsy at all. However it was observed well in GI infections with the incidence declining in the dry season. Brucellosis BAT positive cases showed a very different pattern from others. According to the Department of Microbiology in Mulago Hospital, the incidence suddenly dropped because diagnostic kits had run out; they saved the remaining kits after kits became scarce, and used them only for severe cases until new kits were provided.
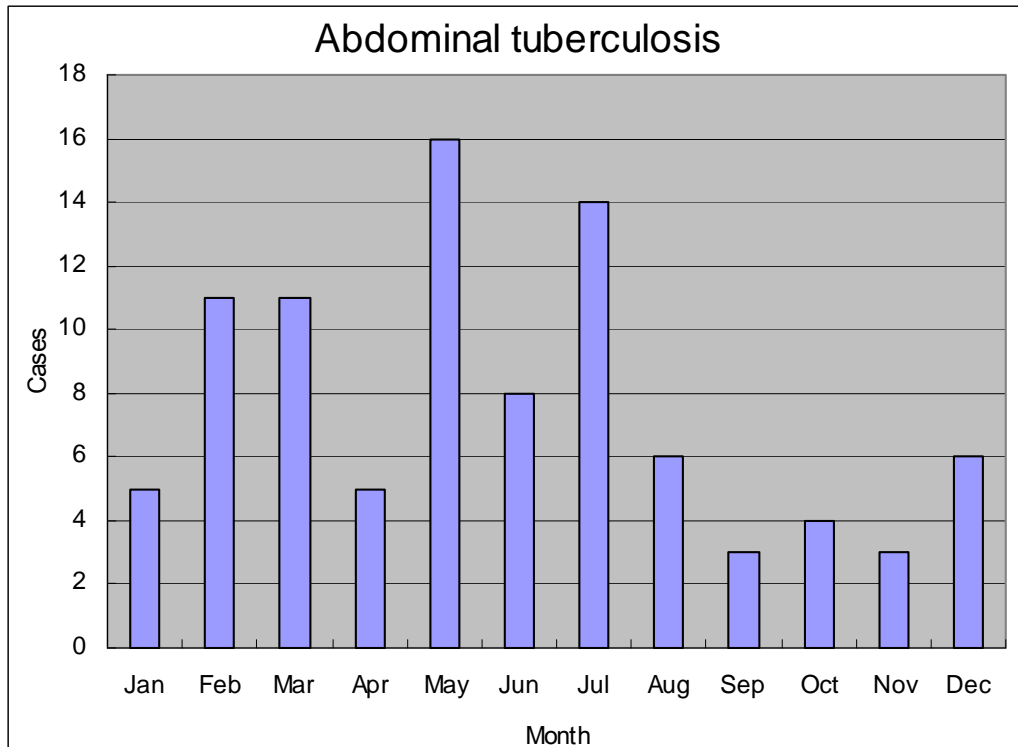
Fig. 4.7 Seasonal patterns seen in the incidence of abdominal tuberculosis in Mulago Hospital
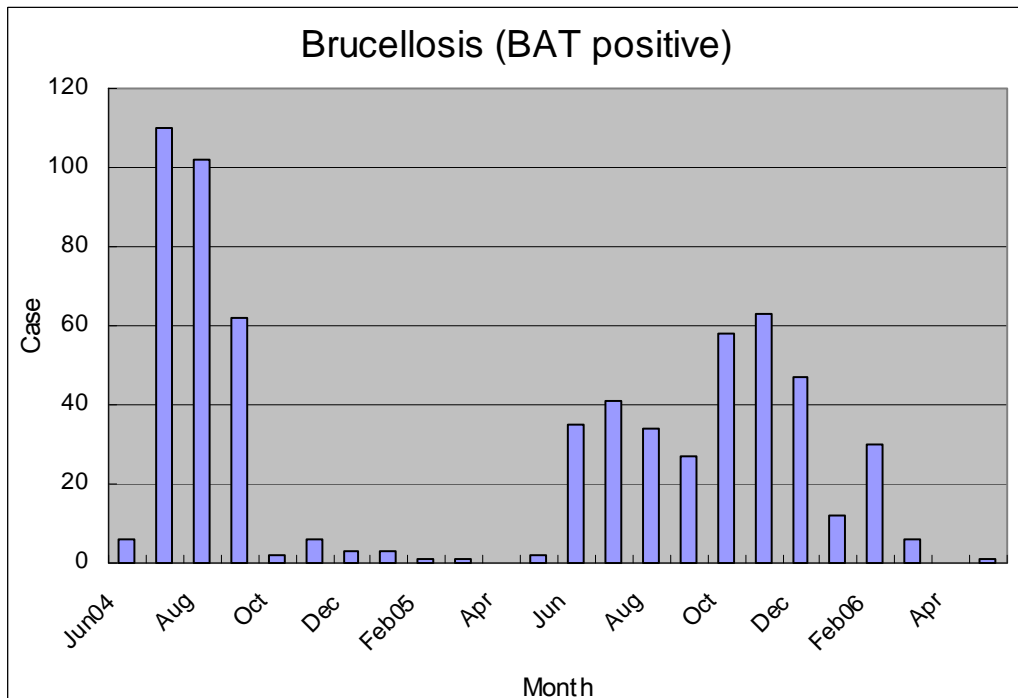
Fig. 4.8 Seasonal patterns seen in the incidence of brucellosis in Mulago Hospital
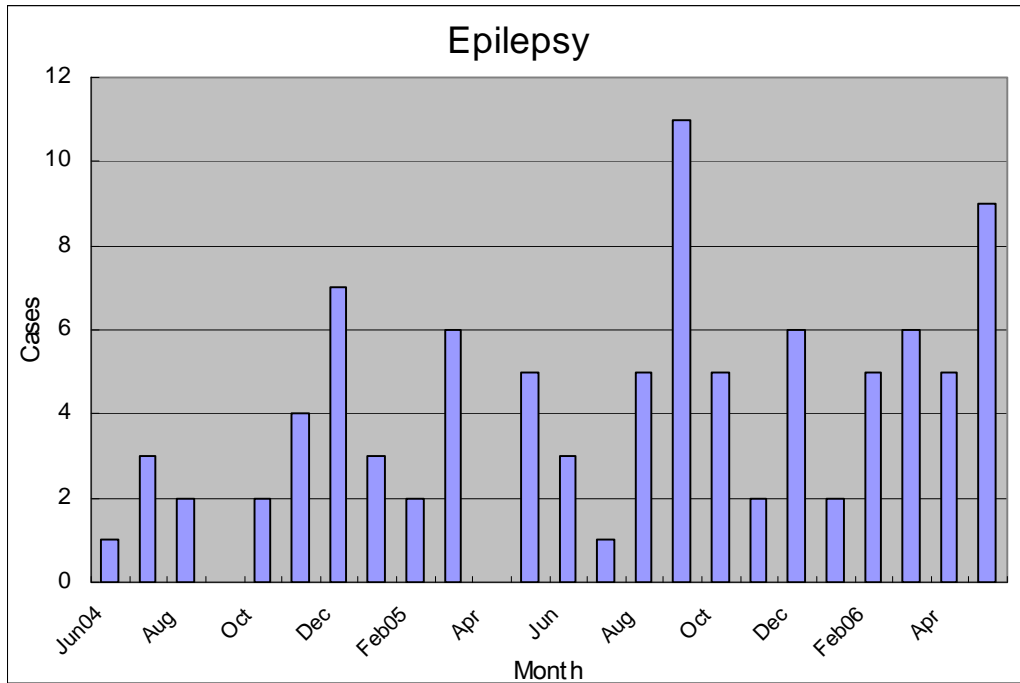
Fig. 4.9 Seasonal patterns seen in the incidence of epilepsy in Mulago Hospital
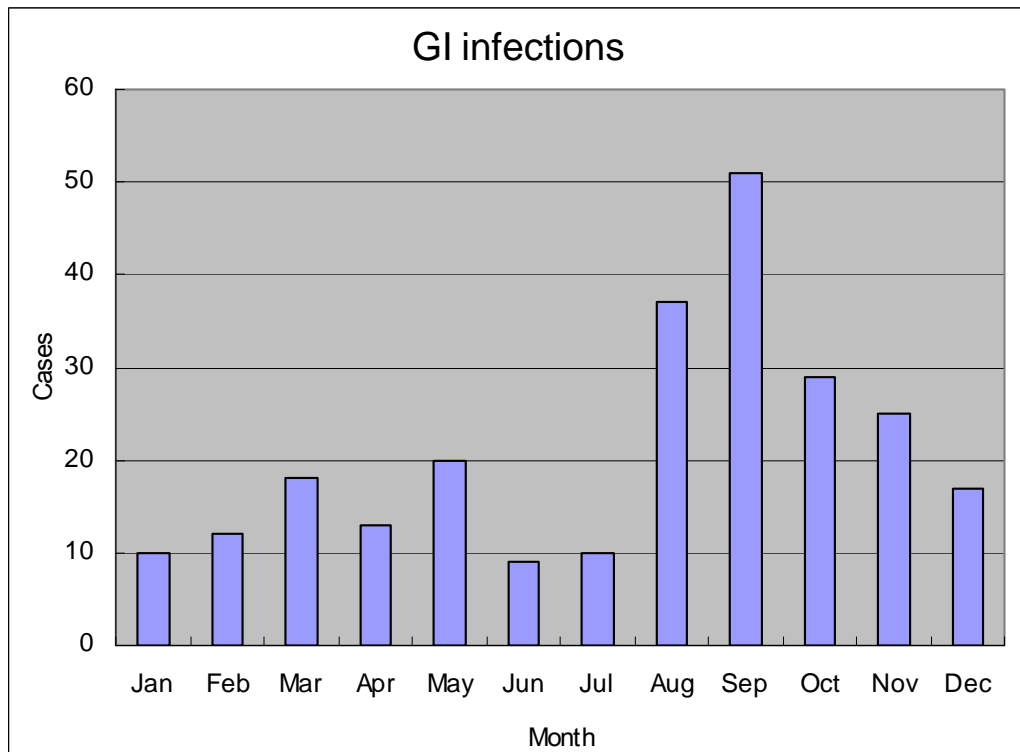
Fig. 4.10 Seasonal patterns seen in the incidence of GI infections in Mulago Hospital

4.4. Discussion

This was the very first study in Kampala, Uganda to screen all zoonotic diseases affecting urban and peri-urban populations using medical records. The hospital was selected in an objective manner to make sure that the populations in the whole of urban and peri-urban areas have access to it. The epidemiological information could be more accurate and free from socioeconomic and geographic biases if different types of health service units were also studied. However, according to our examination of health service seeking trends in the different development types and levels of urbanicity, Mulago Hospital was proved to be accessible by all these different types of LC1s.

The most important zoonotic diseases in and around Kampala were *M. bovis* tuberculosis, brucellosis, cysticercosis, GI infections and fungal diseases such as candidiasis, tinea and tinea capitis. In terms of severity of disease and from the zoonotic point of view, *M. bovis* tuberculosis, brucellosis, cysticercosis, and GI infections were most important, and more precise research on humans are required.

The disease summary of abdominal TB showed that male patients were older than female. It was consistent with the other study of HIV-associated pulmonary TB in Uganda (Nsubuga 2002). The reason for this common gender effect is not known. *M. bovis* was reported to have caused 80% of abdominal TB (12/15) in USA (Veeragandham 1996). However, the figure may be different in Kampala. A study on the proportion of tuberculosis cases due to *M. bovis* in Kampala is required. Also household level studies on gender, environment, TB of family members and cooking behaviour will be useful and supportive information.

Brucellosis affected significantly more females than in males in Kampala. Sex was not a risk factor for brucellosis in Italy (Torre 1997) or in Arak in Iran (Sofian 2008). Being male was a significant risk factor for brucellosis in Greece (Minas 2007) and in Yazd, Iran (Salari 2003) because of occupation. However, the proportion of households keeping cattle is not high in urban areas of Kampala (Chapter 3). Studies on purchasing, cooking, and consumption behaviour at household level may be required to understand the reason for this. In our study, female brucellosis patients were significantly older than male patients, and infection with brucellosis started at a young age and widely affected active ages. In Italy, infection rate increased with age regardless the sex (Torre 1997). In Arak, Iran, age was not a risk factor for human brucellosis (Sofian 2008). The findings in this study cannot be interpreted unless further studies are carried out at the household level. However, because of the limitation of time, household surveys were not conducted during the present study.

Unnatural seasonal pattern of brucellosis incidence revealed the problem of provision of diagnostic kits in Mulago Hospital. The number of 2 year BAT positive patients (652) did not reflect the real magnitude of this disease affecting Kampala city. Considering the existence of the other large missionary hospitals and small-scale clinical laboratories in Kampala, and the lack of diagnostic kits in Mulago Hospital, there would have been a much greater number of incidence of brucellosis every year. Since this is a huge public health problem, risk analysis of transmission of the disease is urgently required. A series of brucellosis studies on the cattle prevalence and risk analysis in the market chain for milk in Kampala was therefore conducted by the author, which is described in later chapters.

The data summary for epilepsy showed the dominance of male epilepsy patients. This difference has not been reported elsewhere, and it might suggest that female epilepsy patients did not have equal access to health services. The age distribution in this study showed a bimodal peak of which the first larger peak was in the age group under 10 years old. This distribution differs from that in UK (PRIMIS+ 2008) where the number of patients increases from 0-4 age group to 20-24, but after that, the numbers of patients remains almost same level until old age. The difference between this and the results in Kampala suggests that most of the epilepsy patients visit Mulago Hospital at onset of the disease. The observed bimodal epilepsy onset age with infant and adolescent peaks was reported by Doherty (2003) in the USA. The second peak of epilepsy patients (onset) did not suggest the evidence of NCC.

This suggests that tests on patients with epilepsy (PWE) and neurological problems for neurocysticercosis (NCC) by serology and/or CT scan are required in Kampala. The author had a chance to see a brain CT scan image of a severe NCC case referred from Democratic Republic of the Congo to Mulago Hospital, but such CT scans for epileptic patients were not common because of the very high cost involved (personal communication at Department of Radiology in Mulago hospital). Given that pig production is increasing significantly in the ESA region especially in Uganda (Phiri *et al.* 2003) and as we have seen the high risk of NCC in the market chain of pork in Chapter 3, such testing would be very useful.

The disease summary of GI infections showed that they affect infants who can easily die by severe dehydration caused by such infections. The seasonal pattern matched

with rainfall suggested the majority of infections were due to unhygienic water supplies. Provision of hygienic drinking water, toilets and sewage lines are urgently required for the control of GI infections. A large proportion of GI infections might be caused by zoonotic pathogens as described in section 4.1.4.4. Identification of causal pathogens is another research opportunity strongly required to understand the role of livestock in GI infections, which will improve urban and peri-urban health in Kampala.

5. **Chapter 5 Spatial epidemiology of most significant zoonoses affecting urban and peri-urban human populations in Kampala**

5.1. Introduction

5.1.1. Aim

The aim of this study was to investigate spatial risk factors of abdominal tuberculosis (TB), brucellosis, epilepsy and gastrointestinal (GI) infections in urban and peri-urban areas in Kampala.

These diseases were selected because *Mycobacterium bovis* tuberculosis, brucellosis, neurocysticercosis (NCC), and GI infections were identified to be potentially the most important zoonotic diseases affecting human populations living in urban and peri-urban areas of Kampala; they were identified by screening the medical records of Mulago Hospital where the target populations have access to medical care (Chapter 4, Section 4.3.2).

The disease burden to humans, mode of transmission and the other general information on *M. bovis* tuberculosis, brucellosis, neurocysticercosis (NCC), and GI infections were reviewed in Chapter 4 (Section 4.1.4).

5.1.2. Main objective of spatial statistics and geographical information systems (GIS) in epidemiology

This chapter uses spatial statistics and GIS to investigate spatial risk factors of the diseases under study. The main objective of applying spatial statistics and GIS to disease data is ultimately to assist informed decision making for disease intervention, thorough addressing the following sequence of questions posed by Robinson (2000):

1. What is the spatial distribution of the disease?

2. Can we detect patterns in this distribution?

3. What are the causal factors of these patterns?

4. How can we change these patterns to improve the health of people and their livestock?

5.1.3. Spatial patterns in disease distributions

Spatial patterns in disease distribution, sometimes with a temporal dimension, are obtained from producing a map. Most patterns in disease data involve some kind of spatial clustering (a pattern of points or areas, regardless of value) or spatial autocorrelation (the attributes of points or areas being influenced by their distance from other points or areas) (Robinson 2000). However, there is no clear distinction between clustering and spatial autocorrelation (Robinson 2000).

5.1.4. Statistical tests to investigate spatial clustering
5.1.4.1. Distance methods and quadrat methods

Upton and Fingleton (1985) have described two major approaches used for the analysis of spatial point patterns in general, and both have been applied to disease clustering (Kulldorff 1995). One approach uses a test statistic based on measuring distances between the disease cases while the other is based on studying the variability of case counts in certain subsets of the study region, often called quadrats.

The first approach is so-called distance methods (Kulldorff 1995), and examples are the second order analysis, broadly referred as Ripley's K (Crawley 2002; Ripley 1976; 1988), and second order neighbourhood analysis (Getis 1987). These analyses compare the actual and expected distances between points of similar value. A random Poisson distribution (plotted expected distance between points of similar value) gives a straight line of $y=x$ while the plotted actual distance deviates from the straight line

when the data is clustered.

The methods that rely on the second approach are called quadrat-methods (Kulldorff 1995). Join counting, originated by Moran (1948), is an example of the most basic technique (Cliff 1988). When quadrats (areas, for example districts) have given binomial (also nominal) values, a 'join' of adjacent quadrats have either similar or dissimilar values. Join counting calculates the actual number of dissimilar joins minus expected number of dissimilar joins (under hypothesis of random distribution) divided by the standard deviation (Cliff 1988). Cliff and Haggett (1988) used join count to demonstrate a very high disease clustering of Asian cholera in London in 1849. They gave binomial values to 17 districts above the median level of deaths and 17 districts below the median for the analysis.

5.1.4.2. The Geographic Analysis Machine (GAM)

Most of the tests proposed so far have been tests for overall clustering, but they cannot detect the location. The tests are useful where the location of clusters is not of interest, for example, in an investigation of whether or not a disease is infectious (Kulldorff 1995).

Quadrat methods pose another serious problem, which is their inability to detect clusters unless their boundaries coincide at least roughly with county borders (Kulldorff 1995; Robinson 2000).

Also, the epidemiologist is typically interested in clusters of disease cases only after having adjusted for spatial variations in the density of the background population

itself, because an apparent disease cluster may be explained simply by a clustering of the population itself in that area (Kulldorff 1995).

The Geographic Analysis Machine (GAM) overcame all these three problems. GAM is a quadrat method developed to explore disease data sets for evidence of spatial patterns, and it avoids the risk of obtaining spurious results arising from arbitrary administrative boundaries by assigning population census data to the position of the centroid of each area unit (Openshaw 1987). The GAM uses a series of overlapping circles in which observed and expected numbers of cases are computed for circles, of a variety of radii, with centres at every point of a fine grid (Robinson 2000). Openshaw *et al*. (1988) investigated the spatial relationship between nuclear establishments and childhood leukaemia in northern England using GAM. GAM detected five clusters (2 major and 3 small clusters), but they were not necessarily associated with nuclear establishments (Openshaw 1988).

However, the use of GAM had limitations. GAM tests each detected overlapping circle individually to judge whether the number of cases deviated from what might have been expected if a Poisson distribution existed (Openshaw 1988); but detected clusters might be correlated and a Bonferroni procedure (Abdi 2007) to compensate for multiple testing would be quite conservative (Kulldorff 1995).

Based on Openshaw *et al.* (1987, 1988), Turnbull *et al*. developed Cluster Evaluation Permutation Procedure (CEPP) for the incidence of leukaemia in New York (Turnbull 1990). In GAM, number of cases in every fixed radius of circle was counted and tested whether it significantly exceeded the expected value estimated by

Poisson distribution using the total population contained in the circle. Only significant circles were recorded on the map and the radii of the circles were increased by a specific amount to reflect the test statistic r (Openshaw 1987). However in CEPP, each circle (quadrat) was constructed so as to have the same population size P, rather than the same radius, to overcome the multi-testing problem in GAM (Turnbull 1990). CEPP not only detected overlapping circles, but also correctly addressed the multiple testing problem, albeit only for circles with a pre-determined population size (Kulldorff 1995).

5.1.4.3. Spatial scan statistic

The spatial scan statistic was inspired by the introduction of overlapping circular zones as quadrats by Openshaw *et al*. (1987) and the solution by Turnbull *et al*. (Turnbull 1990) for circular zones with a fixed population (Kulldorff 1995). The statistic is based on likelihood ratio rather than *ad hoc* test statistics, and a separate test for each possible cluster location or each possible cluster size in not necessary. The likelihood ratio test takes into account a non-homogeneous population density (Kulldorff 1995).

In the statistic, the study region is at first partitioned into geographic sub-divisions called cells, which have the co-ordinates of its geographical or population centroid, number of individuals and disease cases. The cell centroids form irregular lattice. Then circular 'zones' whose centroids are on another lattice are generated as in CEPP, and the circles comprise all individuals in those cells whose centroids lie inside the circle. Different from GAM and CEPP, the radii of circles, which represent values of test statistics, vary continuously from zero upwards. The test statistic is the

likelihood ratio based on the null hypothesis of complete spatial randomness. Monte Carlo methods (Hope 1968) are used to sample cases at random from all individuals in the cells for 999 replicates, and each value of test statistic is calculated. A collection of 1000 values is ranked, and if the observed value is among the 50 highest of these values, the cluster is statistically significant at the 5% level (Kulldorff 1995).

The spatial scan statistic was further developed to apply likelihood ratio test and Monte Carlo methods for Poisson model which requires information about the location of cases and population counts (the underlying population is Poisson-distributed), Bernoulli model which requires information about location of a set of cases and controls (Kulldorff 1997). Since 2006, the spatial scan statistic had become available as downloadable free software, SaTScan (Kulldorff 2006). SaTScan includes more functions such as the space-time permutation model (Kulldorff 2005), ordinal model (Jung 2005), and exponential model (Huang 2005), and it can be used for pure spatial, pure temporal, and space-time analyses (Kulldorff 2006).

This study uses SaTScan for sets of case and control data, and population data in parishes for evidence of spatial clustering.

5.1.4.4. Spatial risk factors for diseases of public importance

There are many studies on public health that investigated the spatial risk factors that caused disease clustering. Here, two examples are introduced.

John Snow's map of deaths from cholera in Soho, London in 1854 is a good example of early work on spatial risk factor. Cliff and Haggett sited his description on the magnitude of the outbreak 'within 250 yards of the spot, there were 500 fatal attacks of cholera in ten days' (Cliff 1988; Snow 1854). Producing the map, the water pump in Broad Street was found to be the source of the outbreak.

Another more recent example is the outbreak of sleeping sickness involving 119 cases between December 31, 1998 and June 2, 2000 in Soroti District in Uganda. A case-control study was conducted for evidence of disease clustering using SaTScan. The statistic detected a significant disease clustering close to a livestock market at the start of the outbreak ($p<0.001$). As the outbreak progressed, the average distance of cases moved away from the cattle market (0.014km/day, $p<0.001$). The results were interpreted to show that the disease was introduced by cattle infected with the causal parasite, *Trypanosoma brucei rhodesiense*, brought to the cattle market from an endemic sleeping sickness focus (Fevre *et al.* 2001). Other examples of the use of SaTScan include an early warning system for West Nile virus outbreak in USA (Mostashari 2003), spatial distribution of bovine spongiform encephalopathy in Ireland (Sheridan 2005), bovine brucellosis in Northern Ireland (Abernethy 2006), and societal and spatial characteristics of colon, lung, and breast cancer in Japan (Fukuda 2005).

5.1.5. Control selection in a case-control study

The case- control study is a useful method of studying areas where the underlying population is not homogeneous and a precise population census is not available, as in the present study of urban and peri-urban areas in developing countries. However, the selection of appropriate controls is often one of the most difficult aspects of case-control design (Dohoo 2004), because it produces bias when controls are unrepresentative of the population that produced the cases (Maclure 1991).

5.1.5.1. The study base

Before introducing the methodologies, two terms should be defined; primary study base and secondary study base. The study base is the population from which the cases and controls are obtained. The primary study base is the target population from which cases and controls come. The secondary study base is one step removed from the actual source population; for example, patients who attended referral clinics from which both cases and controls come (Dohoo 2004). In this study, only the secondary study base is used.

5.1.5.2. Selecting controls in risk-based designs

In this approach, controls are selected from among individuals that did not become cases up to the end of the risk period. This design is appropriate if the population is closed (i.e. there are no additions to the population for the duration of the study and few to no losses), and the risk period for the outcome in an individual has ended before subject selection begins (Dohoo 2004). In this study, hospital records were researched. As new patients data is consistently entering the records, a rate-based design, the alternative, should be used to select controls.

5.1.5.3. Selecting controls in rate-based designs

In rate-based designs, controls are selected from the source population whose exposure distribution matches the population to which the cases belong (Dohoo 2004). In secondary-base studies, selecting non-cases from the same registry is preferable to obtaining them from a different source. This is necessary to reflect the same exposure patterns between cases and controls. To avoid bias with respect to the distribution of exposure in controls, exposure should not be related to admission of non-cases to the registry. Controls should be selected from diagnostic categories that are not associated with exposure (Dohoo 2004).

5.1.5.4. Matching

Matching is the process used to make sure the distribution of the 'matched' factor is the same in the groups being compared. The method used is to select a specified number of non-cases from the risk set matched which prevents confounding and increases the power of the study. However, it has the disadvantages of introducing a selection bias into the data. The stronger the exposure confounder association in the source population, the greater the bias is introduced (Dohoo 2004). Unmatched selection by contrast selects controls from the source population.

5.1.5.5. Neighbourhood controls

When random sampling is not possible especially in a primary-base study, choosing neighbours of cases might suffice. However, by this selection, overmatching is likely to be present (West 1988).

5.1.5.6. The issue of representativeness

It is not important that cases are representative of all cases and that controls are representative of all the non-cases. Cases and controls may be restricted in any logical manner the investigator chooses. This might restrict extrapolation of results but will not affect validity (Dohoo 2004).

5.1.5.7. More than one control per case

There are case-control studies matching two controls per case (1:2 matching) such as Nseir *et al*. (Nseir 2008). When the number of cases is small, the precision of estimates can be improved by selecting more than one control per case (Dohoo 2004). However, the benefits of increasing the number of controls per case are small, and often 3-4 controls per case is the practical maximum (Breslow 1987).

5.2. Materials and methods

5.2.1. Study site

A series of case-control studies was conducted in urban and peri-urban areas of Kampala, the capital of Uganda, based on the medical records of Mulago National Referral Hospital (Mulago Hospital, Fig 5.1).
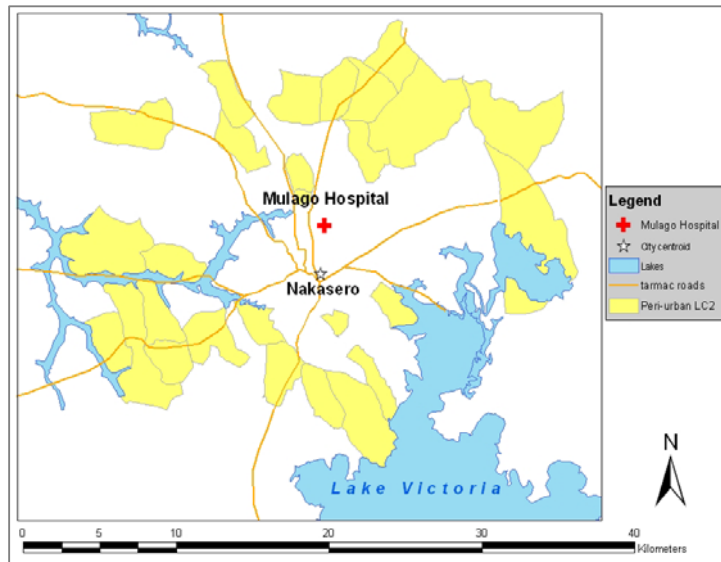
Fig. 5.1 Map of Kampala showing Mulago Hospital and city centroid, Nakasero. Yellow areas are peri-urban parishes (LC2).

5.2.2. Ethics

The ethicality of this project was assessed and approved by the Uganda National Council for Science and Technology (UNCST) and access to the medical records of Mulago Hospital was granted by the Director General Health Services, Ministry of Health, Uganda on 21st November 2005 (refer to Chapter 4, Section 4.2.2.1).

5.2.3. Collection of the information of cases

Four diseases, abdominal tuberculosis (TB), brucellosis, epilepsy and gastrointestinal (GI) infections were investigated in this study. The methodology of the collection of the information of cases was described in Chapter 4, Section 4.2.2.4.

5.2.4. Selection of controls

To avoid bias with respect to the distribution of exposure in controls, controls should be selected from diagnostic categories that are not associated with exposure (Dohoo 2004). For this reason, since all of the selected diseases were infectious diseases, control disease was selected from non-infectious diseases. The digitised medical record summary in Mulago Hospital (this does not include individual patient records) from March 2005 to February 2006 was investigated for non-infectious diseases; cancer, fracture, injury, trauma and tumour were found to be the non-infectious diseases with highest frequencies. Among them, fracture had the largest number especially in younger age groups, which the selected diseases also had in large proportion. Therefore, fracture was selected as the control disease. Fracture has a unique characteristic in that most of the patients are admitted to hospital for a while, which means they are registered as inpatients. In secondary-base study, selecting non-cases from the same registry is preferable to obtaining them from a different source, so that exposure distribution matches with the population to which the cases belong (Dohoo 2004). However, from given the above characteristics of fracture, controls were selected from inpatient records of fracture. Actually, cases themselves were collected from different registries as explained in the previous section. Nevertheless, as Mulago Hospital is accessed by almost all populations living in urban and peri-urban areas of Kampala (Chapter 4, Section 4.3.1), the exposure, defined here, to live in urban and peri-urban areas of Kampala does not differ significantly among these registries. One possible bias is that fracture patients might be more often referred from smaller health facilities than the studied zoonotic diseases.

5.2.5. Case-control matching

Fracture patients, the controls, were matched with cases, with 1:1 matching (match one control with one case) on the basis of age group (<1, 1-9, 10-14, 15-19, 20-49, 50-64, ≧65), sex and month of attendance. In each category, when the number of fracture patients was larger than the number of cases, the same number of controls as the cases was randomly selected using a random number generated in Microsoft Excel (Microsoft Office XP, Redmond, USA). Conversely, in each category, when the number of fracture patients was smaller than the number of cases, all fracture patients in the category were regarded as controls, and the same number of cases as the fracture patients was randomly selected to match with the controls.

5.2.6. Geographical data

In the inpatient records of fracture and TB, LC1 (Village), LC2 (Parish), and LC3 (Sub-county) of the patients was recorded correctly; however in outpatient registration books, the information was recorded in an informal manner with either LC1 or LC2 recorded. All of the recorded locations in and around Kampala were visited and their Global Positioning System (GPS) records were taken with a hand-held GPS (Garmin, Olathe, KS, USA), then the LC2 names were judged by comparing with polygon shape files of LC2s in ArcGIS 9 Geographic Information System (ESRI Systems, Redlands, CA, USA). The polygon shape files of LC2s in Uganda were obtained from the Land and Surveys Department, Ministry of Land Housing and Urban Development of Uganda. The National Biomass Study, from which the spatial data layers were obtained, was provided by the Universal Transverse Mercator (UTM) projection, with detailed parameters as shown in Box 2.2, Chapter 2 Section 2.2.5. GPS data were collected in latitude/longitude format,

in the WGS 84 datum, and were converted to the Biomass projection for processing of maps using ArcView 3.1.

The numbers of the cases and controls within each LC2 were added up to obtain correct numbers at LC2 level. The Cartesian coordinates of the centroids of LC2 polygons were calculated using Center of Mass extension (Jenness 2006) in ArcView 3.1.

5.2.7. Classification of level of urbanicity in the LC2s

This study compares the spatial risks of selected diseases among three levels of urbanicity; urban, peri-urban and rural. LC2s where case and control patients resided were visited and classified into three levels of urbanicity. The definitions of levels of urbanicity were described in Chapter 2, Section 2.2.8. The definitions in Chapter 2 were developed at the LC1 level but they were applied at the LC2 level in the present study since the information about location of patients was collected at LC2 level. To reduce the bias from respondents, in each LC2 more than one respondent who lived in the LC2 was interviewed to determine the percentage of full-time farming households, dominant crop production type (backyard or larger field), speed and source of population change. When the respondents spoke English, they were interviewed directly by the author in English. However when the respondents were non-English speakers, they were interviewed by the author in Luganda language for which he had been trained. The driver of the research vehicle who speaks both English and Luganda supported the author when the answer was not simple. The level of urbanicity was judged using the decision tree model and the results were recorded at the LC2 level.

5.2.8. Examination of representativeness of the cases

It is not important that the study cases are representative of all the cases and that the controls are representative of all the non-cases, and the restriction of cases and controls in any logical manner does not affect their validity (Dohoo 2004) when the control disease is properly selected from secondary study base in a rate-based study design. However, since the restriction of cases and controls might affect extrapolation of results (Dohoo 2004), representativeness of the cases was investigated comparing the age and geographic distributions between matched and non-matched cases. Age distributions were compared in a back to back histogram (the R code is shown in Fig 5.2) and geographic distributions were compared using maps produced in ArcGIS9.

```
> epi<-histbackback(split(Age,Matching),probability=FALSE,main='Epilepsy')
> barplot(-epi$left,col="red",horiz=TRUE,space=0,add=TRUE,axes=FALSE)
> barplot(epi$right,col="blue",horiz=TRUE,space=0,add=TRUE,axes=FALSE)
```

Fig. 5.2 An example of the R code to produce the back-to-back histogram used to show age distribution. This histogram requires Hmisc which can be obtained from the internet website of The R Project for statistical computing (http://www.r-project.org/)

5.2.9. Statistics

5.2.9.1. Spatial scan statistics

Spatial clustering of abdominal TB, brucellosis, epilepsy, and GI infections was investigated using spatial scan statistics, SaTScan version 7.0.1 (Kulldorff 1997) in the Bernoulli model. For the location of cases and controls, polygon centroids of LC2s were used. The analysis performed was purely spatial and scanning was for the detection of 'high rate' clusters, i.e. the areas with larger number of cases than

expected aggregation. The number of Monte Carlo replications was set to 999. The maximum size of cluster admissible was restricted to 50% of the total population in the study area, and no geographical overlap of clusters was permitted.

5.2.9.2. Influence of proximity to Mulago Hospital

The proximity to the hospital can be a spatial confounding factor for study of human diseases. Due to the health care seeking trend of nearest hospital, medical records from a single health unit may not reveal correct disease foci (Odiit *et al.* 2006). Although Mulago Hospital was shown to be accessed from in and around Kampala (Chapter 4, Section 4.3.1), the relationship between numbers of cases and controls per square kilometre and the distance to Mulago Hospital was examined in each disease to test the hypothesis that disease clusters were confounded by this factor. The location of Mulago Hospital was recorded with a hand-held GPS (Garmin, Olathe, KS, USA), then converted to Biomass projection. Although the hospital and the LC2 centroids were presented on a map, the format of the hospital was still in latitude/longitude and Euclidean distance could not be calculated. However, since the hospital showed exactly the same location as the centroid of Mulago I LC2 in Kawempe Division, Cartesian coordinates of the LC2 were used instead.

The areas of LC2s were obtained from the Land and Surveys Department, Ministry of Land Housing and Urban Development of Uganda. The numbers of cases and controls per square kilometre was obtained by dividing the numbers of cases and controls in each LC2 by the area.

The Euclidean distances between LC2 centroids of cases and controls, and Mulago

Hospital were calculated using ArcView 3.1 Geographic Information System (ESRI Systems, Redlands, CA, USA). Since Mulago Hospital is located in an urban area, the influence of the hospital can be also confounded by the influence of city centroid largely at far distance from the hospital. Cases and controls whose LC2 centroids located within 10km distance from Mulago Hospital were then selected for analysis.

Box Cox transformation (Box 1964) was used to estimate the transformation parameter, lambda that was close to zero for all studied diseases. Therefore, the numbers of cases and controls per square kilometre were log-transformed, then the relationship between the transformed numbers and distance to Mulago Hospital was analysed using analysis of covariance (ANCOVA) using the statistics software R 2.4.1. For presentation of the results, numbers of cases and controls per square kilometre over the distance from Mulago Hospital is shown in original scale (exponential of log-transformed data). Fitted regression lines of log-transformed data are also shown in original scale using obtained intercept (a) and slope (b); $y = \exp(a + bx)$.

5.2.9.3. Association of urbanicity to the diseases

The association of urbanicity to abdominal TB, brucellosis, epilepsy and GI infections was measured by calculating an exposure odds ratio and 95% confidence interval of living in each level of urbanicity; urban, peri-urban, and rural areas. The methodology of odds ratio calculation for a case-control study is shown in Formula 5.1 (Thrusfield 2005). Confidence intervals were calculated using logarithmic-based method shown in Formula 5.2 and 5.3 (Thrusfield 2005; Woolf 1955). Calculations were done manually using statistics software R 2.4.1

The exposure odds ratio: OR

$$OR = \frac{(a \times d)}{(b \times c)}$$ (Formula 5.1)

When a, b, c, d are categorised as in Table 5.1.

Table. 5.1 Relationship between urbanicity and the disease

	Case	Control
One level of urbanicity	a	b
The other levels of urbanicity	c	d

The variance of log OR: var

$$var = \frac{1}{a} + \frac{1}{b} + \frac{1}{c} + \frac{1}{d}$$ (Formula 5.2)

The confidence interval (95%): CI

$$CI = OR \times \exp(-1.96\sqrt{var}), OR \times \exp(+1.96\sqrt{var})$$ (Formula 5.3)

Firstly, all selected cases and controls for the spatial scan statistics were selected for the analysis. Due to the nature of fracture (patients tend to be referred from smaller and less facilitated health service units from anywhere in Uganda), results might be confounded by patients referred from outside the Kampala economic zone. Since the purpose of this test is to examine the effects of urbanicity in and around Kampala, secondary, cases and controls living in the LC2s within 20 km from Kampala City centroid were examined.

5.3. Results

5.3.1. Matching

Table 5.2 shows the numbers and proportions of abdominal TB, brucellosis, epilepsy, and GI infections cases matched with controls. Most of abdominal TB (91.9%) and epilepsy (86.3%) cases were able to be matched. However, brucellosis cases were less easily matched (73.9%), and less than a half of cases of GI infections were able to be matched (41.6%). Therefore, age and geographical distributions of matched and non-matched cases were compared to examine the representativeness of the matched cases as follows.

Table. 5.2 Matching fractions in the case-control studies

Disease	Traced	Matched	Matching fraction
Abdominal TB	86	79	91.9%
Brucellosis	337	249	73.9%
Epilepsy	95	82	86.3%
GI infections	250	104	41.6%

5.3.1.1. Abdominal tuberculosis

Fig 5.3 shows the age distributions of matched and non-matched abdominal TB cases. Only a few cases were not matched (blue histogram).
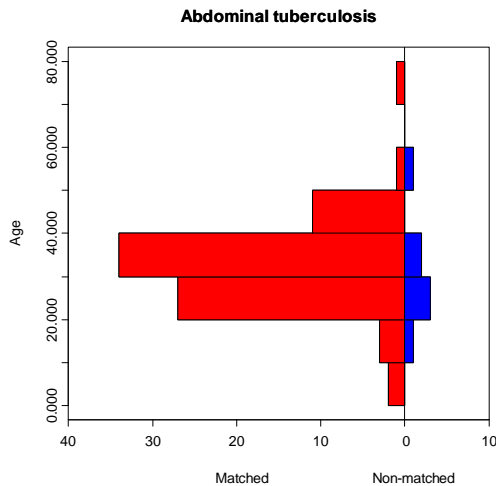
Fig. 5.3 Back to back histogram of age distributions of matched and non-matched abdominal TB cases. Left histogram (red) is matched cases and right histogram (blue) is non-matched. Length of histogram shows frequency. Y axis shows age between 0 and over 80 years old.

There was no obvious difference between the geographical patterns of matched and non-matched abdominal TB cases (Fig 5.4).
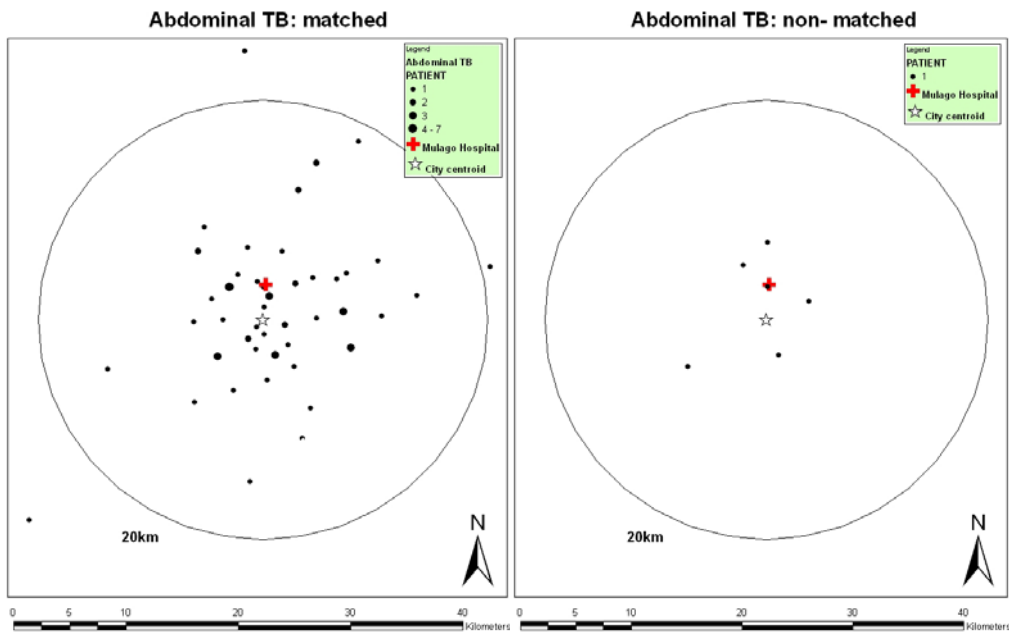
Fig. 5.4 Spatial distributions of matched and non-matched abdominal TB cases. The circles are 20km radii from Nakasero, Kampala. The red 'cross' represents Mulago Hospital.

5.3.1.2. Brucellosis

Fig 5.5 shows the age distributions of matched and non-matched brucellosis cases. Matched (red) and non-matched (blue) cases are showing similar age distributions.
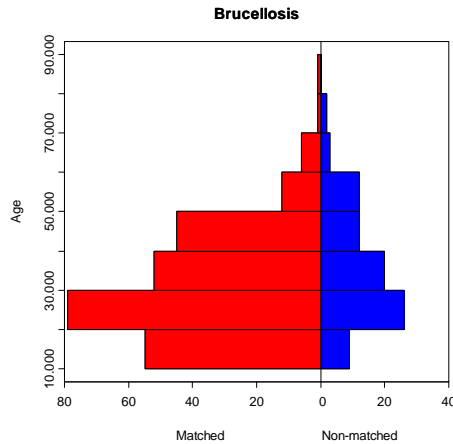
Fig. 5.5 Back to back histogram of age distributions of matched and non-matched brucellosis cases. Left histogram (red) is matched cases and right histogram (blue) is non-matched. Length of histogram shows frequency. Y axis shows age between 10 and over 80 years old.

Matched and non-matched brucellosis cases showed similar concentration patterns close to the Mulago Hospital, especially at its northwest (Fig 5.6).
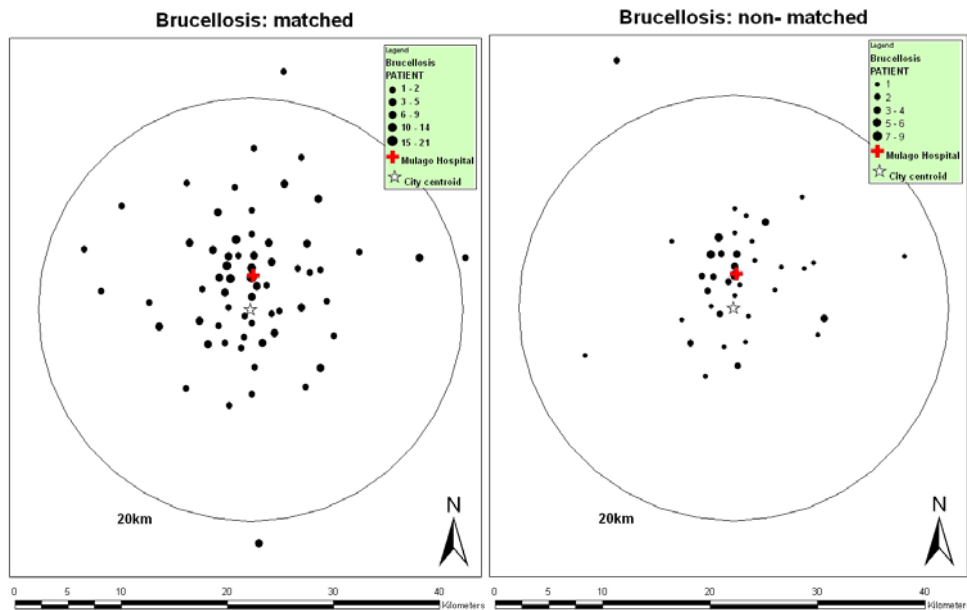
Fig. 5.6 Spatial distributions of matched and non-matched brucellosis cases. The circles are 20km radii from Nakasero, Kampala. The red 'cross' represents Mulago Hospital.

5.3.1.3. Epilepsy

Matched and non-matched epilepsy cases also showed similar age distributions (Fig 5.7).
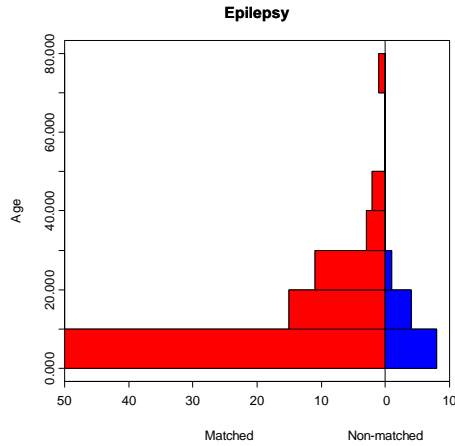
Fig. 5.7 Back to back histogram of age distributions of matched and non-matched epilepsy cases. Left histogram (red) is matched cases and right histogram (blue) is non-matched. Length of histogram shows frequency. Y axis shows age between 0 and over 80 years old.

In Fig 5.8, a concentration of matched cases in the area north to west of Mulago Hospital, was observed, but not observed in non-matched cases. However, the number of non-matched cases (13) was small.
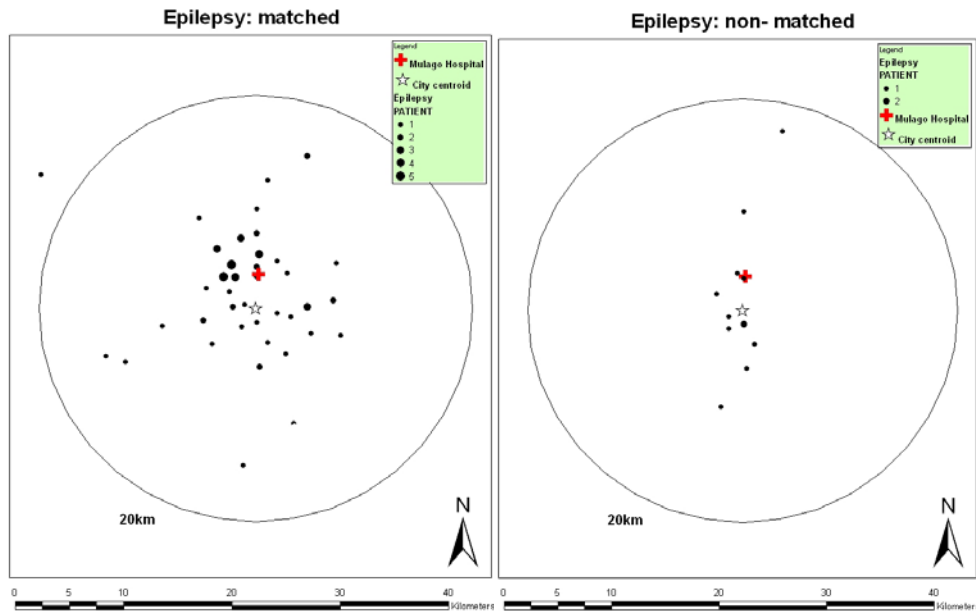
Fig. 5.8 Spatial distributions of matched and non-matched epilepsy cases. The circles are 20km radii from Nakasero, Kampala. The red 'cross' represents Mulago Hospital.

5.3.1.4. GI infections

Due to the large number of GI infections cases in children below 10 years old, such a large number of GI infections cases were not able to be matched with controls (Fig 5.9).
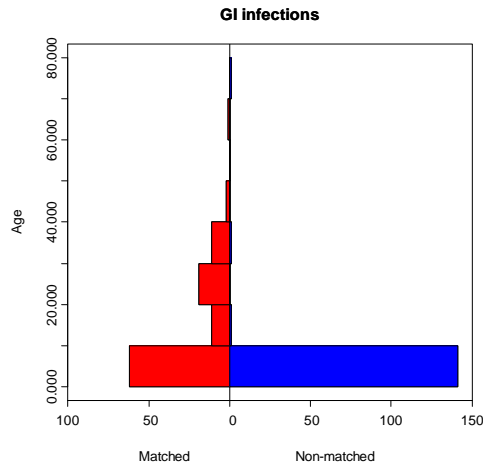
Fig. 5.9 Back to back histogram of age distributions of matched and non-matched GI infections cases. Left histogram (red) is matched cases and right histogram (blue) is non-matched. Length of histogram shows frequency. Y axis shows age between 0 and over 80 years old.

The spatial distributions of matched and non-matched GI infections cases showed very similar patterns (Fig 5.10).
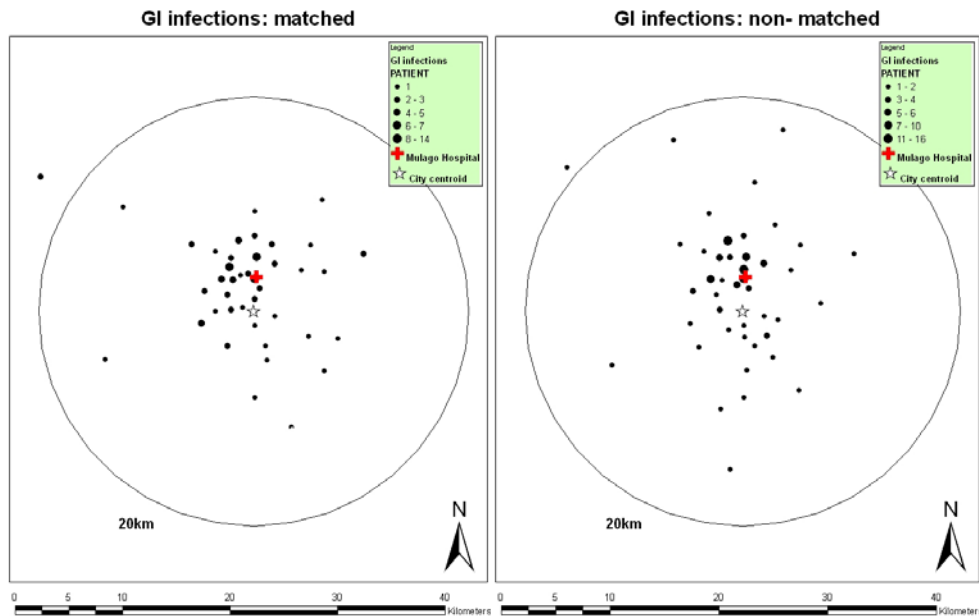
Fig. 5.10 Spatial distributions of matched and non-matched GI infections cases. The circles are 20km radii from Nakasero, Kampala. The red 'cross' represents Mulago Hospital.

5.3.2. Spatial scan statistics

5.3.2.1. Abdominal tuberculosis

Fig 5.11 shows the spatial distributions of abdominal TB cases and controls in and around Kampala. The spatial scan statistic did not detect any statistically significant most likely disease cluster nor any secondary cluster.
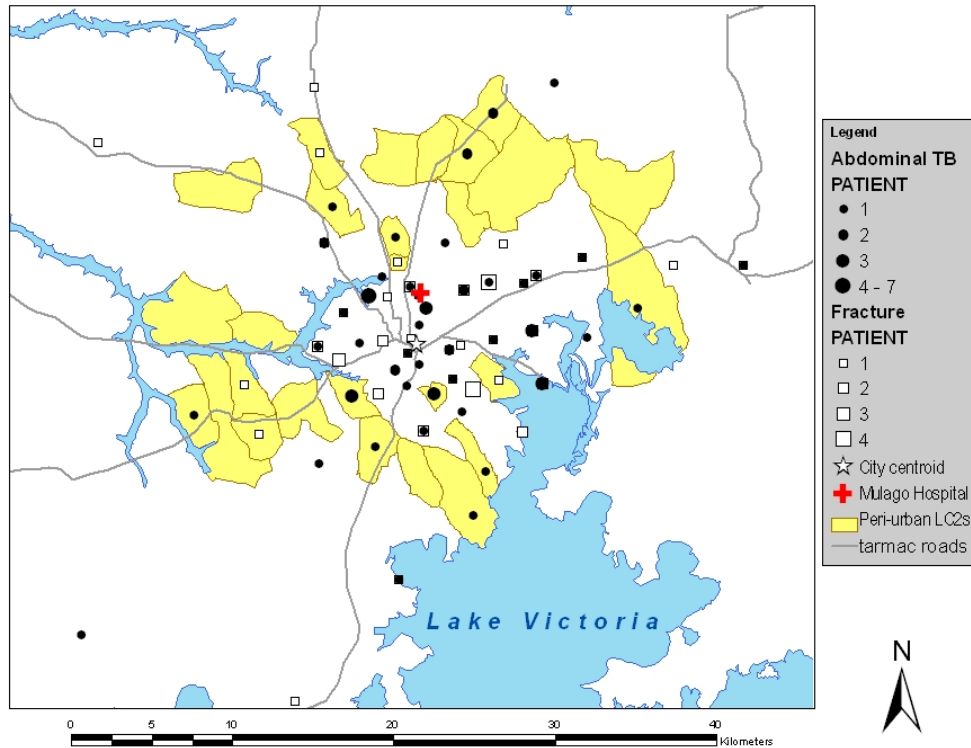
Fig. 5.11 Map of Kampala showing spatial distributions of abdominal TB cases and controls. Black points are cases. White squares are controls. The red 'cross' represents Mulago Hospital. Yellow areas are peri-urban parishes. Grey lines are tarmac roads. No disease cluster was detected with spatial scan statistic.

5.3.2.2. Brucellosis

Fig 5.12 shows the spatial distributions of brucellosis cases and controls. The spatial scan statistic detected a most likely cluster (6.8 km radius, *p*=0.001) which included Mulago Hospital (Fig 5.12, Box 5.1). No significant secondary cluster was detected.
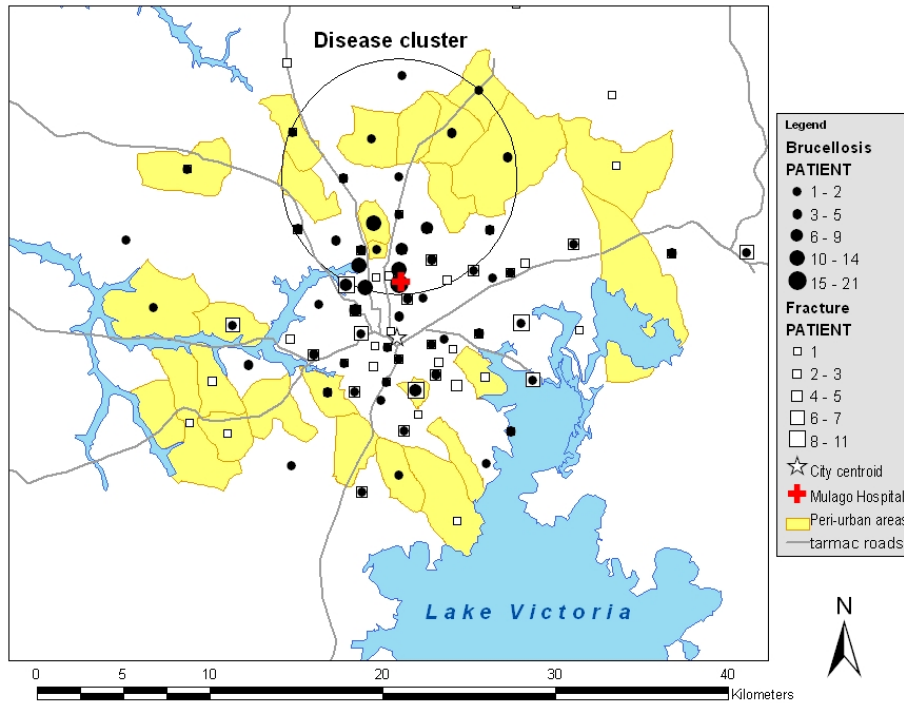
Fig. 5.12 Map of Kampala showing spatial distributions of brucellosis cases and controls. Black points are cases. White squares are controls. The red 'cross' represents Mulago Hospital. Yellow areas are peri-urban parishes. Grey lines are tarmac roads. A most likely disease cluster was detected with the spatial scan statistic (radius 6.8km, *p*=0.001). No significant secondary cluster was detected.

Box 5.1 The most likely cluster of brucellosis

Cartesian coordinates: 453063, 244159	Observed / expected...: 1.557
Radius..: 6826.59 m	Relative risk.........: 2.160
Population............: 167	Log likelihood ratio..: 40.594856
Number of cases.......: 130	Monte Carlo rank......: 1/1000
Expected cases........: 83.50	P-value...............: 0.001

5.3.2.3. Epilepsy

Most of the epilepsy cases were from in and around Kampala, but some cases were from as far away as the extreme south west and east Uganda. The spatial scan statistic detected a large most likely cluster including a part of Kampala (76.9 km radius, *p*=0.001, Fig 5.13, Box 5.2).
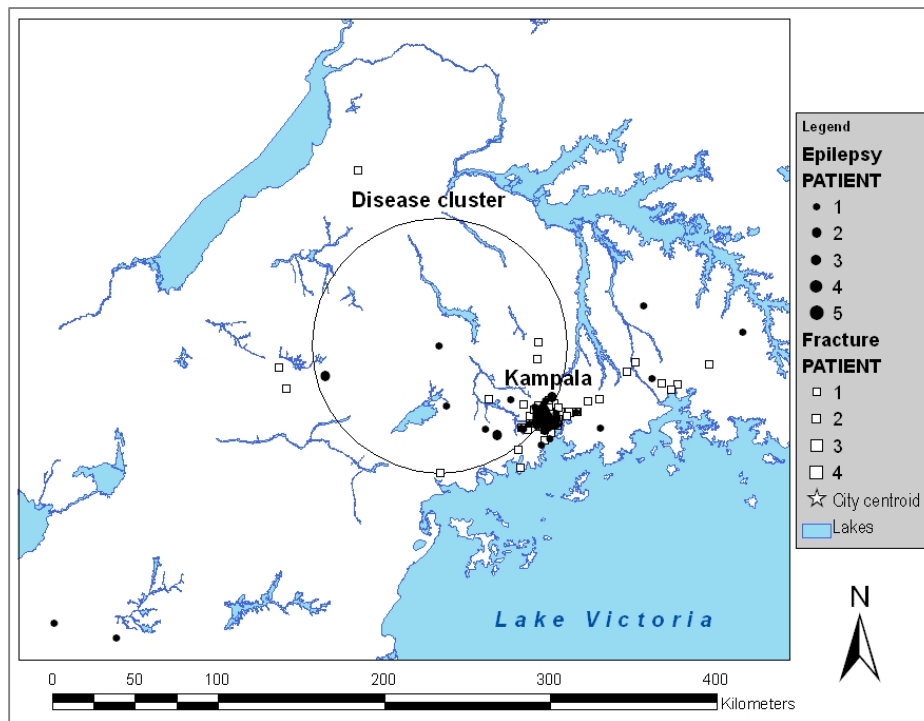
Fig. 5.13 Map of Uganda showing spatial distributions of epilepsy cases and controls. Black points are cases. White squares are controls. A large most likely disease cluster including a part of Kampala was detected with the spatial scan statistic (radius 76.9 km, *p*=0.001).

Box 5.2 The most likely cluster of epilepsy	
Cartesian coordinates: 389847,280178	Observed / expected...: 1.375
Radius….: 76902.23 m	Relative risk.........: 2.168
Population............: 80	Log likelihood ratio..: 11.382160
Number of cases.......: 55	Monte Carlo rank......: 1/1000
Expected cases........: 40.00	P-value...............: 0.001

Fig 5.14 shows the spatial distributions of epilepsy cases and controls in and around Kampala. The large most likely cluster included Mulago Hospital and a concentration of cases northwest of the hospital. No significant secondary cluster was detected.
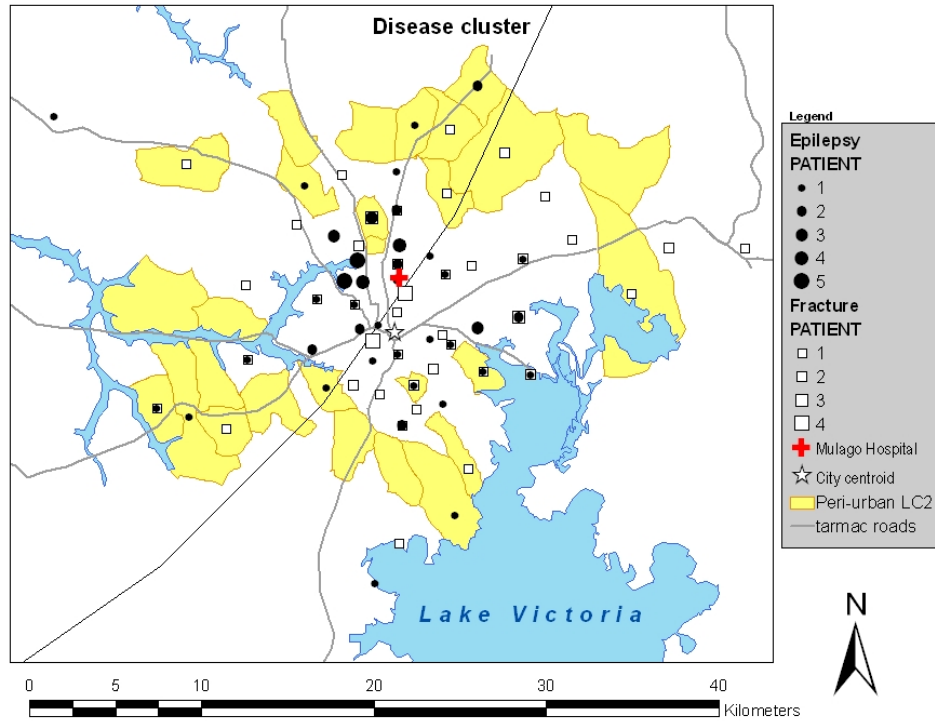
Fig. 5.14 Map of Kampala showing spatial distributions of epilepsy cases and controls. Black points are cases. White squares are controls. The red 'cross' represents Mulago Hospital. A large most likely disease cluster (radius 76.9 km, *p*=0.001) included Mulago Hospital.

5.3.2.4. GI infections

Fig 5.15 shows the spatial distributions of GI infections cases and controls in and around Kampala. The spatial scan statistics detected a most likely cluster (4.8 km radius, p=0.001) which included Mulago Hospital (Fig 5.15, Box 5.3). No significant secondary cluster was detected.
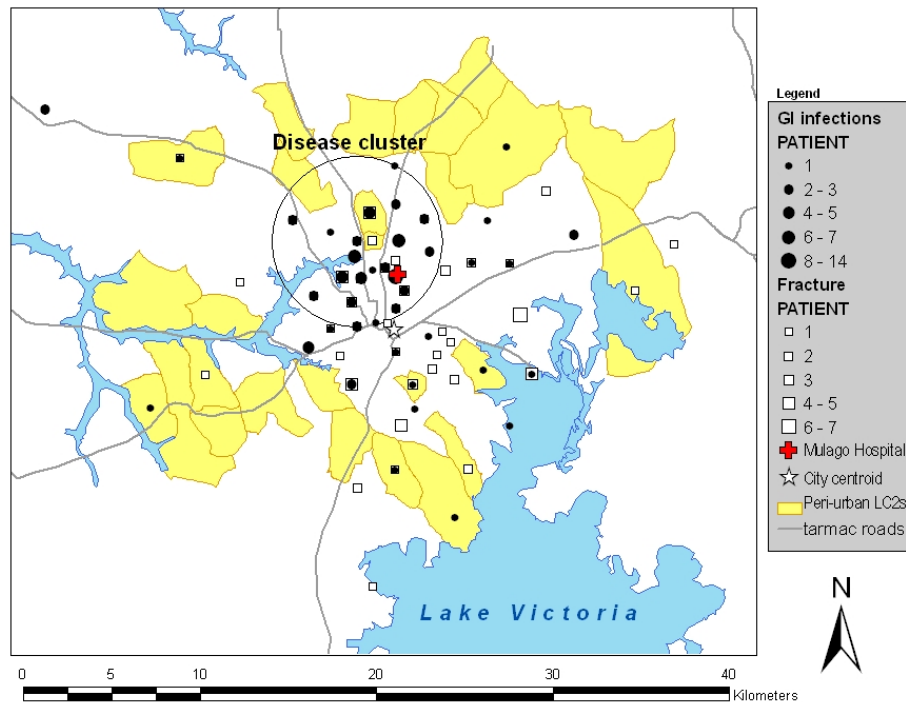
Fig. 5.15 Map of Kampala showing spatial distributions of GI infections cases and controls. Black points are cases. White squares are controls. The red 'cross' represents Mulago Hospital. Grey lines are tarmac roads. A most likely disease cluster (radius 4.8 km, p=0.001) included the hospital.

Box 5.3 The most likely cluster of GI infections	
Cartesian coordinates: 450875, 239866	Observed / expected...: 1.392
Radius….: 4835.38 m	Relative risk.........: 2.262
Population............: 102	Log likelihood ratio..: 15.951823
Number of cases.......: 71	Monte Carlo rank......: 1/1000
Expected cases........: 51.00	P-value...............: 0.001

5.3.3. Influence of proximity to Mulago Hospital

The influence of proximity to Mulago Hospital was examined to test the hypothesis that disease clusters were confounded by the influence. For the test, cases and controls residing in the LC2s where the centroids are located within 10 kilometres from Mulago Hospital were selected (Table 5.3).

Table. 5.3 Numbers of cases and controls involved for the test of influence of proximity to Mulago Hospital

	Case	Control
Abdominal tuberculosis	29	24
Brucellosis	128	91
Epilepsy	35	37
GI infections	45	37

5.3.3.1. Abdominal tuberculosis

Fig 5.16 shows the relationship between number of abdominal TB cases per square kilometre and distance from Mulago Hospital. Proximity to Mulago Hospital of the abdominal TB cases was not significant; log number of cases did not change linearly over distance from the hospital (slope=-0.147, se=0.114, p=0.204, Fig 5.16 shows in the original scale, not in log). The slope of controls (slope=-0.093, se=0.180) was not significantly different from that of cases (p=0.764).
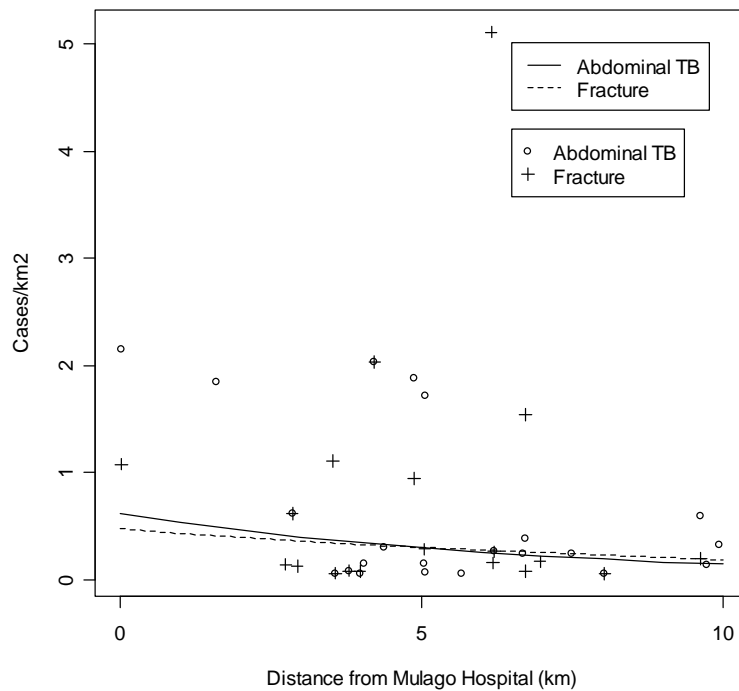
Fig. 5.16 Comparison of abdominal cases and controls in the relationship between number of patients per square kilometre and distance from Mulago Hospital. Proximity to the hospital was not significant (p=0.204). The relationships of cases and controls were not significantly different (p=0.764).

5.3.3.2. Brucellosis

The influence of proximity to Mulago Hospital was observed in brucellosis cases; log number of brucellosis cases declined linearly with the distance from the hospital (slope=-0.298, se=0.119, *p*=0.015, Fig 5.17 shows in original scale). However, the slope was not significantly different from that of controls (slope=-0.118, se=0.176, *p*=0.311).
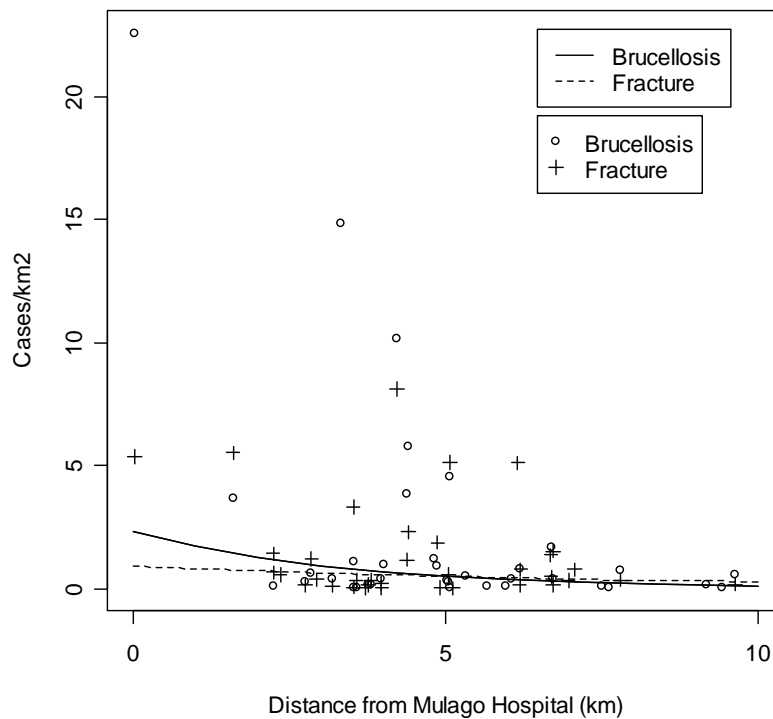
Fig. 5.17 Comparison of brucellosis cases and controls in the relationship between number of patients and distance from Mulago hospital. The influence of proximity to the hospital was significant (*p*=0.015). However, the relationships of cases and controls were not significantly different (*p*=0.311).

5.3.3.3. Epilepsy

The influence of proximity to Mulago Hospital was not observed in epilepsy; log number of cases in epilepsy did not change linearly over distance from Mulago Hospital (slope=-0.161, se=0.110, p=0.150, Fig 5.18 shows in original scale). The slope of controls (slope=-0.262, se=0.170) was not significantly different from that of cases (p=0.556).
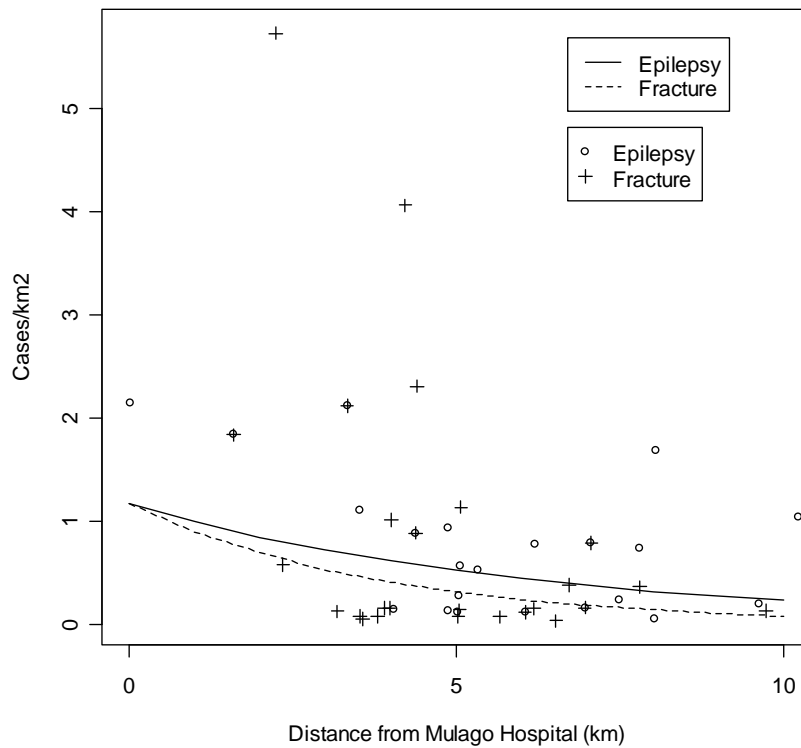
Fig. 5.18 Comparison of epilepsy cases and controls in the relationship between number of patients and distance from Mulago Hospital. The influence of proximity to the hospital was not significant (p=0.150). The relationships of cases and controls were not significantly different (p=0.556).

5.3.3.4. GI infections

Although statistically not significant, the influence of proximity to Mulago Hospital was observed in GI infections cases; log number of GI infections cases declined linearly with the distance from the hospital (slope=-0.231, se=0.116, p=0.055, Fig 5.19 shows in original scale). The slope of cases was not significantly different from that of controls (slope=-0.093, se=0.162, p=0.398).
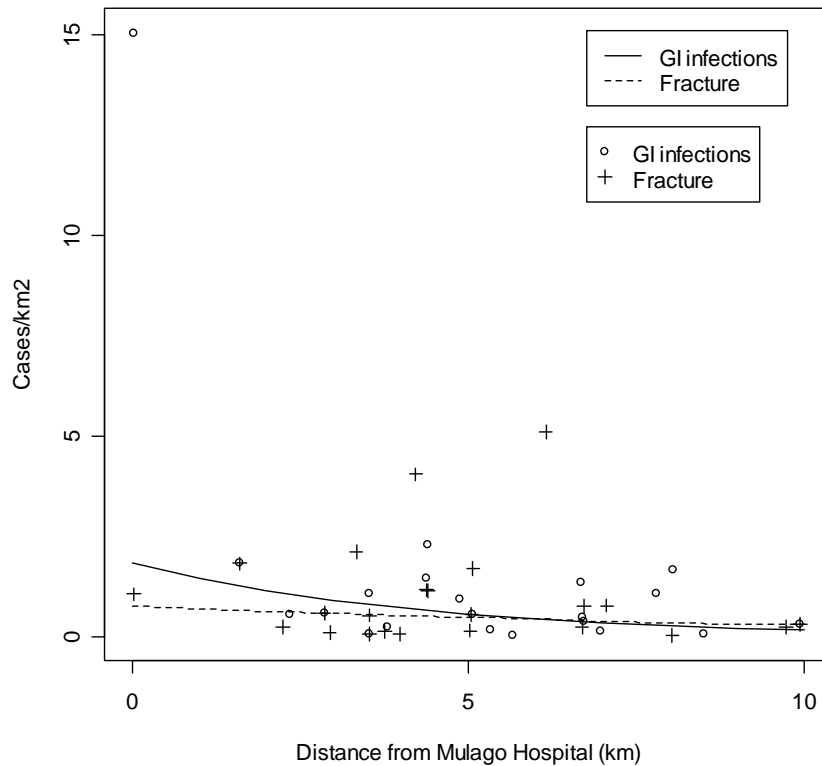
Fig. 5.19 Comparison of GI infections cases and controls in the relationship between number of patients and distance from Mulago hospital. Although statistically not significant, the influence of proximity to the hospital was not significant (p=0.055). The relationships of cases and controls were not significantly different (p=0.398).

5.3.4. Association of the level of urbanicity to the diseases

The association of level of urbanicity with abdominal TB, brucellosis, epilepsy, and GI infections was measured by calculating an exposure odds ratio and 95% confidence interval. Table 5.4 shows the numbers of all cases and controls selected for the spatial scan statistic. Cases and controls of rural in Table 5.4 include patients reside outside the Kampala economic zone.

Table. 5.4 Numbers of all cases and controls in each level of urbanicity

	Case				Control			
	Urban	PU	Rural	Total	Urban	PU	Rural	Total
Abdominal TB	53	11	15	79	51	5	23	79
Brucellosis	208	16	25	249	172	11	66	249
Epilepsy	59	5	18	82	56	7	19	82
GI infections	91	4	9	104	79	6	19	104

When all these cases and controls were included for the analysis, living in urban areas was a significant risk factor for brucellosis (odds ratio 2.27, 95% CI 1.48-3.49) and GI infections (odds ratio 2.22, 95% CI 1.06-4.62, Table 5.5). Also, living in rural areas was a significant preventative factor for brucellosis (odds ratio 0.31, 95% CI 0.19-0.51, Table 5.5). There was no significant risk factor for abdominal TB and epilepsy.

Table. 5.5 Exposure odds ratios and their 95% confidence intervals to urbanicity for all cases and controls

	Urban	Peri-urban	Rural
Abdominal TB	1.12 (0.58-2.16)	2.39 (0.79-7.24)	0.57 (0.27-1.20)
Brucellosis	2.27 (1.48-3.49)	1.49 (0.68-3.27)	0.31 (0.19-0.51)
Epilepsy	1.19 (0.61-2.33)	0.70 (0.21-2.29)	0.93 (0.45-1.94)
GI infections	2.22 (1.06-4.62)	0.65 (0.18-2.39)	0.42 (0.18-0.99)

However, this figure changed dramatically when the cases and controls living within 20km from Kampala City centroid were selected. Table 5.6 shows the numbers of cases and controls served for the analysis.

Table. 5.6 Numbers of cases and controls within 20km from Kampala City centroid and the level of urbanicity

	Case				Control			
	Urban	PU	Rural	Total	Urban	PU	Rural	Total
Abdominal TB	53	11	3	67	51	5	3	59
Brucellosis	208	16	6	230	172	11	5	188
Epilepsy	59	5	2	66	56	7	3	66
GI infections	91	4	4	99	79	6	3	88

All of the significant relationships found in the previous analysis disappeared both from brucellosis and GI infections; all of the confidence intervals included 1 (Table 5.7). There was no significant association of level of urbanicity with any of the diseases; i.e., the risks of abdominal TB, brucellosis, epilepsy and GI infections were not significantly different among urban, peri-urban, and rural areas.

Table. 5.7 Exposure odds ratios and their 95% confidence intervals to urbanicity in the areas within 20km from Kampala City centroid

	Urban	Peri-urban	Rural
Abdominal TB	0.59 (0.23-1.54)	2.12 (0.69-6.51)	0.88 (0.17-4.51)
Brucellosis	0.88 (0.45-1.73)	1.20 (0.54-2.66)	0.98 (0.29-3.26)
Epilepsy	1.51 (0.54-4.23)	0.69 (0.21-2.30)	0.66 (0.16-2.70)
GI infections	1.30 (0.48-3.52)	0.58 (0.16, 2.11)	1.19 (0.26-5.49)

5.4. Discussion

In this study, spatial clustering was observed for brucellosis, epilepsy, and GI infections. However, the fact that all of the disease clusters included the Mulago Hospital might suggest involvement of the confounding factor, proximity to the hospital. Influence of proximity to Mulago Hospital was found in brucellosis and GI infections cases; however the influence was not significantly different from their controls.

On the other hand, spatial clustering was not observed in abdominal TB cases. A key to understanding the difference between abdominal TB and the other studied diseases was the difference of the source registry of medical records used in the disease selection. Both fracture (control disease) and abdominal TB were investigated using inpatient records whilst brucellosis, epilepsy, and GI infections were investigated from outpatient records. In Mulago Hospital, inpatients are likely to be referred from smaller and less facilitated health service units sometimes from far away with patients seeking the best affordable medical care. The high reputation and popularity of Mulago Hospital amongst people residing in all of urban, peri-urban, and rural areas of the Kampala economic zone was proved in Chapter 4 (Section 4.3.1). The disease clusters of outpatients reflected the 'catchment area' of Mulago Hospital. The maps (Fig 5.13, 5.15, and 5.16) showed the concentration of cases in the areas along/between three tarmac roads, namely Hoima Road, Bombo Road, and Gayaza Road, from west to east. Because the 'catchment area' is large enough, the difference of the influence of proximity to the Mulago Hospital between cases and controls was not significant. Other parts of Kampala should have had easier access to the other hospitals avoiding entering the city centre area. However, these results should be

interpreted with caution. The disease clusters included some slum areas, and many of the cases came from these areas. Chapter 2, Section 2.3.6 showed the location of slum areas close to the Mulago Hospital, which coincided with the concentration of all abdominal TB, brucellosis, epilepsy, and GI infections cases. These cases might well be associated with low hygiene in these areas.

Separate analysis of the association of the level of urbanicity to abdominal TB, brucellosis, epilepsy, and GI infections showed an interesting contrast between all cases and controls, and those living within 20km distance from the Kampala City centroid, Nakasero. In the analysis of all selected cases and controls, living in urban areas was a significant risk factor for brucellosis and GI infections, and living in rural areas was a preventative factor. However, no risk factor was found amongst the cases and controls residing within 20km distance from the city centroid. This was caused by the health seeking behaviour of fracture patients who are likely to be referred to Mulago Hospital even from whole parts of Uganda with emergency units. The results from cases and controls living within 20km from the city centroid was thought to be more reliable because the above bias was removed, and showed that the level of urbanicity was not associated with the incidence of abdominal TB, brucellosis, epilepsy and GI infections.

Interpretation of the results so far looked as if no highly significant factor had been uncovered. It is said that 'geographical analysis will never prove or establish causation, only suggest, stimulate and inform: maybe that is more than sufficient' (Openshaw 1996). Indeed, the results provided very important information that the risks of zoonotic diseases might be homogenous in urban, peri-urban, and rural areas

of Kampala economic zone. They did not show that the risks are low in any part of Kampala. Instead, it should be concluded that whole areas have high risks of zoonoses in terms of the numbers of cases found. Moreover, it must be noted that the size of urban population is far larger than that of peri-urban and rural areas in the Kampala economic zone. Since all of the target zoonoses, *Mycobacterium bovis* tuberculosis, brucellosis, cysticercosis and GI infections are food borne diseases, hygiene in the market chains could be examined further.

Brucellosis was the most significant zoonosis affecting human populations living in the Kampala economic zone, in terms of the number of cases. In other countries, prevalence of human brucellosis was significantly higher in rural areas (1.1%) than in urban areas (0.46%) in serum tube agglutination test in Bolu Province, Turkey (Karabay 2004). Similarly, prevalence of brucellosis was higher in rural areas (1.3 +/- 0.005 % and 1.25 +/- 0.009 %) than in urban areas (1.23 +/- 0.001% and 1.12 +/- 0.01 %) using agglutination test and ELISA respectively in Assiut Governorate in Egypt (Hussein 2005). In Greece where brucellosis in cattle is still endemic, the urban population was not at risk of acquiring brucellosis because all commercialized dairy products were produced from pasteurized milk (Minas 2007). However in Uganda, the risk of human brucellosis was not different among urban, peri-urban and rural areas according to the present study. The high risk of brucellosis in urban areas of Kampala may be due to the informal marketing of raw milk infected with *Brucella*. A large proportion of marketed milk was reported to be infected with *Brucella*; using the milk ring test (MRT), 44.4% (n=162) of the marketed milk samples in urban and peri-urban areas of Kampala were positive for antibodies against *Brucella* (Mwiine 2004). Also, brucellosis was widespread in livestock in both urban and peri-urban

areas of Kampala (Lee-Smith 2006); in cattle, 42% (n=245) of the samples were positive for antibodies against *Brucella* using slow serum tube agglutination test (Mwiine 2004). Moreover, high cattle prevalence of brucellosis (55.6%: 95%CI 50.0-61.2) was reported in the largest milk basin of Uganda, Mbarara, which is the largest source of milk sold in Kampala (Bernard *et al.* 2005). Hereafter, this thesis will concentrate on understanding brucellosis in cattle in the Kampala economic zone (in Chapter 6), and the market chain for untreated milk (in Chapter 7), to offer a control strategy for this disease. Since *M. bovis* tuberculosis and some proportion of GI infections are also transmitted through untreated milk, Chapter 7 is particularly relevant for food borne disease control in Kampala.

6. Chapter 6 Prevalence of brucellosis in cattle in urban, peri-urban and rural areas of Kampala

6.1. Introduction

6.1.1. Aims

The aims of this study were:

1) to estimate the prevalence of brucellosis in dairy herds in urban, peri-urban and rural areas of Kampala economic zone

2) to find the risk factors associating with brucellosis in dairy herds and individual animals, and

3) to estimate the extent of *Brucella* infections in urban and peri-urban milk supplies.

The goal of this work was to develop a risk model for infected milk with *Brucella abortus* in urban areas of Kampala related to the great number of human brucellosis cases (described in Chapter 5).

6.1.2. Brucellosis in cattle

Brucellosis in cattle is characterised by abortion and rapid spread of the infections in an unvaccinated cattle herd. In a herd in which disease is endemic, the infected animal typically aborts once after exposure and subsequent gestations and lactations appear normal. However, the establishment of the carrier state in a large proportion of animals may lead to a 20% reduction in the milk yield of infected milking cows, the production of dead calves at term, and an increased frequency of retained placenta (Aiello & Mays 1998). The loss through abortion or calf death is a huge economic constraint for farmers (Birley & Lock 1999). Natural transmission among cattle is by ingestion of the organisms that may be present in large numbers in

aborted foetuses, foetal membranes and uterine discharges. Venereal transmission by infected bulls may occur but this is rare. Cows may become infected through artificial insemination when semen is contaminated (Aiello & Mays 1998).

6.1.2.1. Epidemiology of brucellosis in cattle in Uganda

During July and August in 1972, in cattle, four districts (now sub-regions) of Uganda, Ankole (southwest), Karamoja (northeast), West Nile (northwest) and Tororo (southeast) were surveyed for brucellosis, and their sero-positivities by complement fixation test were 16.3, 12.4, 19.7 and 18.7%, respectively. Approximately 18% of the female cattle were positive for brucellosis (Newton *et al.* 1974). A few years later, using serum agglutination tests at 5 ranches and 10 farms in 5 districts, the prevalence was 19.7% in East Ankole (western), 23.3% in East Acholi (north), 9.0% in East Lango (north), 16.2% in Bulemezi (central) and 1.0% in Entebbe (central). In total, 18.1% of 1,606 tested cattle were positive in Uganda (Ndyabahinduka 1978). In Southern Uganda (Rukungiri District), a study performed on 1,094 cattle from 38 farms found a herd prevalence of 7.5% and an animal prevalence of 3% (Bernard *et al.* 2005; Oloffs *et al.* 1988). A study in the central and southern parts of Uganda (one farm in Kampala, 5 in Mukono and 10 in Wakiso) reported high prevalence of brucellosis at the herd level (56.3%, 9/16) and at the animal level, 5.0% (19/383) using both RBT and serum agglutination test (Nakavuma 1994). More recently, in urban and peri-urban areas of Kampala, 42% (102/245) of the cattle serum samples were positive for antibodies against *Brucella* using slow serum tube agglutination test (Mwiine 2004). Bernard *et al.* (2005) conducted a survey of tuberculosis and brucellosis in the dairy herds of Mbarara District, the most important dairy production areas of Uganda; the Rose Bengal test was used for brucellosis. The herd

prevalence of brucellosis was 55.6% (95% confidence interval 50, 61.2) out of 315 herds and individual animal prevalence was 15.8% (14.8, 16.7) out of 12,764 head of cattle. Ndyabahinduka and Chu (1984) suggested that the high plateau lands of western and eastern Uganda were zones of hyper-endemicity, and the Central and Southern part of the country along the shore of Lake Victoria were zones of moderate endemicity, both of human and bovine brucellosis. A comparative study of brucellosis prevalence among urban, peri-urban and rural areas has not previously been reported in Uganda.

In Queen Elizabeth National Park in Uganda, 2% of 42 free ranging African buffaloes were found to have been exposed to brucellosis (Kalema-Zikusoka *et al.* 2005). Although this percentage was not high, it indicated that wildlife might also be able to transmit the disease. Although some of these results are thought to have had biases (e.g. avoiding testing vaccinated animals) or lacked precision (e.g. too small a number of animals tested), it can be concluded that brucellosis is prevalent throughout the whole of Uganda.

6.1.2.2. Available diagnostic tests for *Brucella abortus* in cattle

There are currently many types of diagnostic tools for *Brucella abortus* in cattle that may be categorised as follows:

1) Conventional serological tests

The 2 mercaptoethanol test, the Card test (Diaz 1979), complement fixation test (CFT) for serum (Diaz 1979) and milk (Hunter 1972), the milk ring test (Nicoletti 1969), the plate agglutination test (Nielsen 1979), the Rivanol test (Lord 1989), the Rose Bengal test (RBT) and the Tube Agglutination Test (TAT)

(Hunter 1972).

2) Precipitation tests

The agar gel immunodiffusion test (Lord 1989), radial immunodiffusion test (Diaz 1979), haemolysin in gel test (Ruckerbauer 1984), and indirect haemolysis test (Sutherland 1982).

3) Primary binding tests

Indirect enzyme-linked immunosorbent assay (IELISA) for serum (Gall 1998) and milk (Gall 2002), competitive enzyme-linked immunosorbent assay (CELISA) (Gall 1998), fluorescence polarisation assay for serum (FPA) (Nielsen *et al.* 1996), milk FPA (Nielsen 2004), bulk milk tank samples FPA (Gall 2002), whole blood FPA (Nielsen 2001), fluorescence immunoassay (FIA) (Hall 1984), and particle concentration FIA (Nicoletti 1993).

4) Isolation of organisms (OIE 2008)

5) Polymerase chain reactions (PCR) (Bricker 2003) and

6) Skin tests (Gall 2004; Saegerman 1999).

For the purpose of screening, conventional serological tests complemented by primary binding assays and Milk Ring Test (MRT) seem to be most popular. MRT has been effective in locating infected herds in official control and eradication programmes on an area basis, but there are a high percentage of false positives (Merck Veterinary Manual 2008).

Antigen serological diagnosis of brucellosis began more than 100 years ago with a simple agglutination test. This type of test was susceptible to false positive reactions, and the results were subjectively scored; such tests were inexpensive, simple and

could be rapid. A number of modifications were developed to establish a rapid screening test with high sensitivity and perhaps less specificity (Nielsen 2002). False positive reactions in screening tests are known to be caused by Enterobacteriaceae such as *Yersinia enterocolitica* 0:9 (Bundle 1984; Diaz-Aparicio 1993; Erdenebaatar *et al.* 2003; Gall 1998; Gall *et al.* 2001; Kittelberger *et al.* 1998; Nielsen 1990b; Portanti *et al.* 2006; Samartino *et al.* 1999) and *Salmonella enterica* Serotype Urbana (Nielsen *et al.* 2007). In addition to these unrelated bacteria, *B. abortus* strain 19 vaccine also gives rise to an antibody response similar to that resulting from field infection (Gall *et al.* 2000). Precipitation tests were developed to distinguish this vaccine antibody from field infections, however they did not perform well and primary binding assays were developed instead (Nielsen 2002). For the control of brucellosis at the national or local level, RBT and buffered plate agglutination test (BPAT) are recommended as suitable tests by The World Organisation for Animal Health (OIE) (2008). Indeed, BPAT showed the best performance index (PI=193.1, perfect score was 200), and RBT was rated 167.6 when above available conventional tests were compared; the sensitivity and specificity of BPAT were 95.4 and 97.7, respectively, and those of RBT were 81.2 and 86.3 (Gall 2004).

However conventional tests need to be complemented by a confirmatory test, usually more complicated but also more specific, to be used on sera that reacted positively in screening tests. CFT is one of the conventional tests which is a widely accepted confirmatory test although it is complex to perform, requiring good laboratory facilities and adequately trained staff to accurately titrate and maintain the reagents (OIE 2008). ELISAs and FPA are primary binding tests recommended by OIE as suitable screening tests for control of brucellosis at the national or local level (OIE

2008). The indirect enzyme-linked immunosorbent assay (IELISA) is a highly sensitive test but it is sometimes not capable of differentiating between antibody resulting from S19 vaccination or other false positive reaction problems from responses induced by pathogenic *Brucella* strains (Nielsen 1990a). The IELISA is therefore used as a screening test rather than a confirmatory test in testing of vaccinated cattle or herds affected by false positive serum reaction (FPSR) problems (OIE 2008). The competitive enzyme-linked immunosorbent assay (CELISA), that uses a monoclonal antibody specific for one of the epitopes of *Brucella* sp. O-polysaccharide has a higher specificity than the IELISA (Nielsen 1995; Stack 1999). The CELISA is capable of eliminating most reactions due to residual antibody produced in response to vaccination with S19 (OIE 2008). The CELISA eliminates some but not all of FPSR due to cross reacting bacteria (Nielsen 2002). Sensitivity and specificity of CELISA is now 100% and 99.9% respectively, and cross reactions for anti LPS antibodies in Enterobacteriaceae positive sera do not occur (Portanti *et al.* 2006). A literature review found FPA to have equal or greater diagnostic accuracy than the other primary binding assays (IELISA and CELISA), less costly, easier to perform (i.e. simple and rapid) and amenable to automation (Gall 2004). Moreover, FPA is more suitable for field based studies because it can be applied for milk (Nielsen 2004), bulk milk tank samples (Gall 2002) and whole blood (Nielsen 2001). The specificity for cattle recently vaccinated with S19 was over 99% (Nielsen *et al.* 1996), but the specificity of FPA in FPSR conditions is currently unknown (OIE 2008). No single serological test is appropriate for brucellosis in every epidemiological situation (OIE 2008) and careful discussion is necessary in selecting tools for serological surveys of brucellosis.

Another alternative approach for the control and eradication of brucellosis is improvement of vaccines. As mentioned above, S19 vaccine induces antibodies to the O-polysaccharide (O-PS) of the lipopolysaccharide which causes false positive cross reactions. Rough attenuated mutant, RB51 vaccine lacks this O-PS and therefore does not cause this cross reaction (Moriyon 2004). However there is disagreement with regard to the efficiency of strain RB51 compared with the protection induced by S19 in cattle (Moriyon 2002; Moriyon 2004; OIE 2008).

6.1.2.3. Risk factors for brucellosis

Risk factors for brucellosis are closely related to its mode of transmission; when a cow aborts, large numbers of organisms are excreted, and the highly contaminated fluids and tissues expelled can be a significant risk to in-contact cattle (Nicoletti 1981). Brucellosis is reported to spread between herds largely through the movement of cattle or by contact at pasture, with associated risk factors including the size, type and density of herds (Abernethy 2006; Kellar 1976; Salman 1984; Sheahan 2002). Age of animal was shown to be a risk factor both in Mbarara, Uganda (Bernard 2005) and in Northern Ireland (Abernethy 2006). Exotic breeds were also more at risk in Mbarara, Uganda (Bernard 2005); on the contrary mixed-breed herds were more at risk than exotic breed herds in Eritrea (Omer *et al.* 2000).

In Africa, a higher prevalence was reported in intensive husbandry systems (8.2%) than mixed crop-livestock system (0.3%) in Eritrea at animal level (Omer 2000) and in humid areas in Côte d'Ivoire, Nigeria and Burkina Faso (Gidel 1976).

6.2. Material and methods

6.2.1. Study sites

Study sites comprised 56 cattle keeping LC1s in the urban (29 LC1s), peri-urban (11 LC1s), and rural areas (16 LC1s) of Kampala economic zone, Uganda (Fig 6.1). Prior to this study, 87 LC1s were randomly selected (Chapter 2). Out of 87 LC1s, 31 LC1s were excluded because 12 LC1s were universities and institutions, and 19 urban LC1s did not have cattle. LC system was described in Chapter 2, Section 2.1.3.
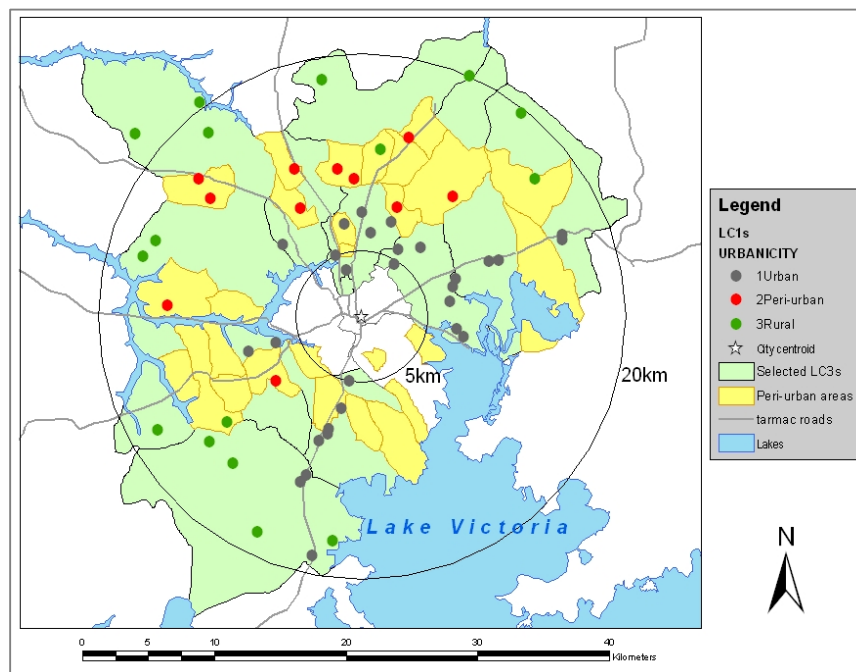
Fig. 6.1 Map of studied 56 cattle keeping LC1s and their levels of urbanicity; 29 urban, 11 peri-urban, and 16 rural LC1s. Yellow areas are peri-urban LC2s confirmed by the author (Chapter 2 and 5).

6.2.2. Study design

6.2.2.1. Sampling framework

The sampling methods were designed with reference to Veterinary Epidemiology (Thrusfield 2005) and Veterinary Epidemiologic Research (Dohoo 2004). Multi-stage sampling was selected for the study using the framework shown in Box 6.1.

Box 6.1 Framework in the multistage sampling

1. External population

 Improved and cross breed and indigenous cows in 10 selected LC3s

2. Target population

 Improved and cross breed and indigenous cows in selected 56 cattle keeping LC1s

3. Primary sampling unit

 Cattle herd

4. Secondary sampling unit

 Milking cow
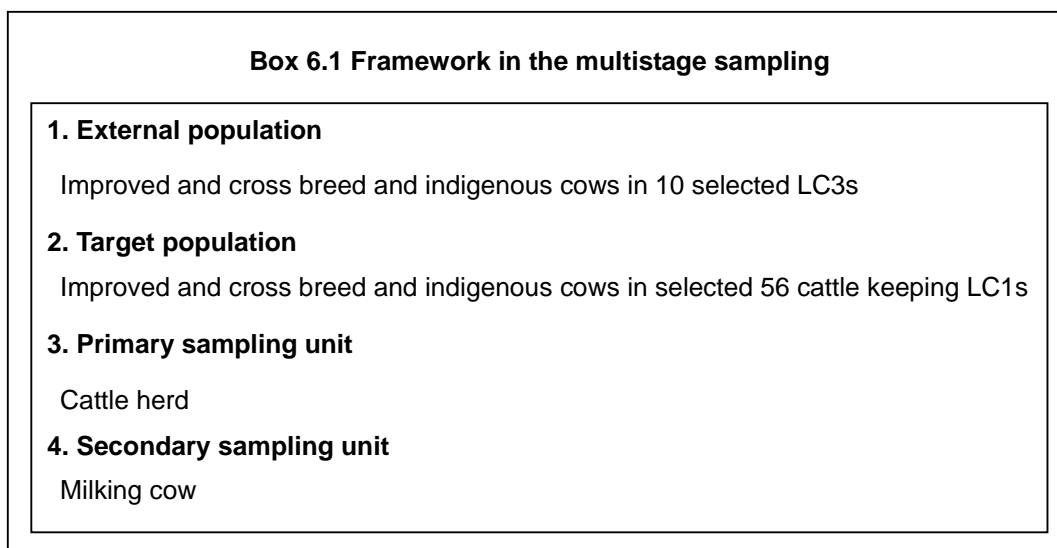
6.2.2.2. Sample size of primary sampling units (cattle herds)

Sample sizes of primary sampling units were calculated based on the total number of cattle herds in the 56 LC1s in and around Kampala, data which was obtained from interviews in the Village Characteristic Survey (VCS, Chapter 2) from September to December 2005. Win Episcope 2.0 (Thrusfield *et al.* 2001) was used to calculate sample size for prevalence estimates. Expected herd prevalence was set to 55.6% based on the brucellosis herd prevalence in Mbarara (Bernard *et al.* 2005), and accepted error and level of confidence were selected as 5% and 95% respectively. The sample fraction, i.e. percentage of herds to sample among total herds in the 56 LC1s, was then calculated by dividing obtained sample size in Win Episcope 2.0 by total number of herds known from VCS. The sample fraction was calculated to

determine the number of cattle farms to be sampled in each LC1 in the field.

6.2.2.3. Sample size of secondary sampling units (milking cows)

Only milking cows including cows in dry period were selected as secondary sampling units; bulls, calves and heifers were excluded from this study. The ultimate purpose of this study was to estimate the quantity of *Brucella* infected milk produced in urban and peri-urban areas for sale in urban areas of Kampala. For this purpose, each *farm* was characterised as either infected with *Brucella* or not, since milk from different milking cows is usually mixed at the farm before selling. To determine whether a farm is free from infection with *Brucella*, or has at least one serologically positive cow, sample size in each farm needs to be calculated for detecting the presence of the disease (Thrusfield 2005). The sample size of cows in each farm for disease detection was calculated using FreeCalc version 2 (Australian Veterinary Animal Health Services) the underlying theory for which is given in Cameron *et al*. (Cameron & Baldock 1998). Sensitivity and specificity were entered as 95.4% and 99.9% respectively as an imperfect test, BPAT, was to be used for this study complemented by CELISA. The sensitivity, 95.4% was taken from the sensitivity of BPAT (sensitivity 0.954, specificity 0.977) (Gall 2004), and the specificity, 99.9% was taken from the specificity of CELISA (sensitivity 1.000, specificity 0.999) (Portanti *et al.* 2006). Estimated cattle prevalence for the calculation was selected as 5%, which is lower than other similar studies; the central and southern parts of Uganda was found to have 8-16% of herds positive (Nakavuma 1994), and in Mbarara, herd prevalence was 55.6% (Bernard *et al.* 2005), in order to test strictly that the farm is free from brucellosis. Calculated sample sizes according to herd size are shown in Box 6.2 where: 'Population' is herd size; 'Diseased' shows estimated

number of diseased animals in the herd at 5% of prevalence; The column 'Type I' shows the probability of Type I error: false rejection of a true null hypothesis, in this case, the probability that a non-infected herd is wrongly judged to be infected; 'Type II' is the probability of a Type II error: a failure to reject the null hypothesis when it is untrue, i.e. the probability that an infected herd is wrongly judged to be free from the disease.

Box 6.2 Sample Size Table for disease detection

Sensitivity: 95.4%, Specificity: 99.9%, Target type I: 0.05, Target type II: 0.05
Prevalence: 5%

Population	Diseased	Sample Size	Reactors	Type I	Type II
20	1	20	0	0.0451	0.0198
40	2	33	0	0.0406	0.0325
60	3	39	0	0.0489	0.0383
80	4	44	0	0.0452	0.0431
100	5	46	0	0.0493	0.0450
120	6	48	0	0.0495	0.0469
140	7	50	0	0.0478	0.0488
160	8	51	0	0.0486	0.0497
180	9	79	1	0.0492	0.0029
200	10	81	1	0.0478	0.0031
220	11	82	1	0.0487	0.0031
240	12	83	1	0.0490	0.0032
260	13	84	1	0.0488	0.0033
280	14	85	1	0.0483	0.0034
300	15	86	1	0.0475	0.0035

6.2.3. Selection of diagnostic tests

No single serological test is appropriate in each and all epidemiological situations for brucellosis; all have limitations especially when it comes to screening individual animals (Godfroid *et al.* 2002; Nielsen 2002; OIE 2004). Therefore a combination of two diagnostic tests was chosen for this study.

The Buffered Plate Agglutination Test, BPAT (Angus 1984) was selected for the screening test, because its performance index was the highest among conventional tests including the Rose Bengal test (RBT) in the comparison of diagnostic tests for brucellosis: cost was low, sensitivity was 95.4%, and specificity was 97.7% (Gall 2004). Competitive enzyme-linked immunosorbent assay (CELISA) was selected as the confirmatory test.

BPAT antigen was purchased from the United States Department of Agriculture, Animal and Plant Health Inspection Service, Veterinary Services, National Veterinary Services Laboratories (Ames, IA, USA). CELISA kits were purchased from the Veterinary Laboratories Agency (Surrey, UK). Both kits were directly sent to Uganda maintaining the cold chain and, immediately after receipt, were kept refrigerated at the Central Laboratory of the Department of Veterinary Medicine, Faculty of Veterinary Medicine, Makerere University exactly as instructed by the suppliers.

6.2.4. Cattle sampling

6.2.4.1. Sensitization and mobilisation

Prior to cattle sampling, the purpose and research protocol of this study was explained at meetings with the District Veterinary Officers (DVOs) of Kampala, Wakiso and Mukono Districts. The DVOs passed on the information to the Sub-county Veterinary Officers (SVO) of the 56 LC1s, and cattle keepers were sensitised through LC1 leaders during September 2007.

After the sampling schedule was determined by agreement between the author and DVOs, SVOs informed the LC1 leaders of the proposed work schedule. LC1 leaders then asked cattle farmers to be at home and to keep zero grazed animals indoors and keep grazing animals tied or close to a crush on sampling days. LC1 leaders were also asked to prepare a list of farmers keeping milking cows in the LC1 by the sampling date.

6.2.4.2. Herd selection

Sample herds were selected on the day of sampling at the LC1. Therefore all cattle farmers had to be ready, and the farmers who were not selected also had to keep the cows in/near the shed at the sampling day. This process made unselected farmers unhappy because many of them were eager to know the test results. However, this approach reduced selection bias caused by SVOs. For example, a SVO might select only friendly farmers, and those farmers might not be a representative sample of all farmers in the LC1. Milking cow keeping farmers were classified as: small or large scale improved and cross breed cattle farmers or small scale or large scale indigenous breed cattle farmers. Then 24% (the sampling fraction) of the farmers were randomly

selected in each category using numbered pieces of paper (the use of sampling fraction, 24% will be described in the results section (Section 6.3.1)).

The pieces of paper were drawn by LC1 leaders or SVOs in a manner such that the numbers could not be seen by the drawer. At each draw, exactly the same number of pieces of paper, numbered continuously from one, with the number of total herds listed in a category was prepared, and each drawn paper was added back to the remaining pieces before the next draw so that the probability of selection did not change. The herd sample size in each category was determined by ending at 24% of the total number of cow keeping farmers in the category. However when the rounded-off herd sample size was calculated as zero, at least one herd was sampled unless there was no herd in the chosen category. A milking cow was defined as any breed of cow used for milking purposes, and had already had one calving: heifers and calves were not regarded as milking cows. Any cattle farms that did not have a cow were excluded from the list of cattle herds before herd selection.

6.2.4.3. Cattle sampling

Cattle sampling was conducted during October and November 2007. Animals were restrained using wooden cattle crushes or roped by herdsmen, SVO, a technician or the author. Blood was taken by the author from either jugular or sacral medial vein of a cow using 21 gauge needles and disposable 5ml plastic syringes. Needles and syringes were used only once and then discarded. Blood was kept in plain vacuum plastic tubes (vacutainer®) and left for 30 minutes to 1 hour at ambient temperature to separate serum from the blood clot. Serum was collected from the vacutainer using a disposable plastic Pasteur pipette, poured in an Eppendorf tube and stored in a

cooler box in the field. Eppendorf tubes were then stored in the freezer at -20˚C. The 9 points body condition score, using half point increments from 0 to 5 (van Niekerek 1982), was recorded for all sampled cows.

6.2.4.4. Diagnostic tests

Collected sera were stored and tested for brucellosis using BPAT at the Central Laboratory in the Department of Veterinary Medicine, Faculty of Veterinary Medicine, Makerere University, Uganda. The BPAT was performed as described in the Manual of Diagnostic Tests and Vaccines for Terrestrial animals (OIE 2004). A glass window was modified and used for the test, as the commercial transparent glass plate for the agglutination test was not available in Makerere University.

CELISA was performed at the Molecular Laboratory, Department of Molecular Biology, Faculty of Veterinary Medicine, Makerere University. As the number of sampled cows did not exceed the capacity of the CELISA kit prepared for the study, all serum samples were tested using both of BPAT and CELISA.

6.2.5. Interviews with the farmers

During the cattle sampling, cattle owners were interviewed for information about their farms and milking cows using a questionnaire (Appendix III). The contents of the questionnaire are shown in Box 6.3.

Interviews were conducted for English speakers in English, and for non-English speakers in Luganda by the author. The SVOs and the driver of the research vehicle assisted with the interviews as they spoke both English and Luganda well.

Data from interviews and diagnostic tests were digitized using Microsoft Access (Microsoft Office XP, Redmond, USA).

Box 6.3 Contents of the interview with cattle owner

1. Farm information

Name of owner, farm type, number of cattle, milk sales destination, boiling practice before sales, source of cattle, price of milk, abortion, insemination, brucellosis vaccination, and family members with undulant fever or diagnosis for brucellosis

2. Milking cow information

Name or ear tag number, breed, colour, age, milk yielding per day, number of delivery, abortion, year of abortion, and source of cows

---

6.2.6. Statistical analysis

6.2.6.1. Agreement between BPAT and CELISA

Agreement between BPAT and CELISA results was tested using the *kappa* statistic (Thrusfield 2005) to estimate the degree of false positive cross reactions with the BPAT. Table 6.1 shows the relationship between BPAT and CELISA results. The *kappa* statistic was calculated as following:

Table. 6.1 Relationship between BPAT and CELISA

	CELISA positive	CELISA negative
BPAT positive	a	b
BPAT negative	c	d

Formula 6.1 The observed proportion agreement between 2 tests, OP

$$OP = (a + d)/n, \quad \text{when} \quad n = (a + b + c + d)$$

Formula 6.2 Expected proportion agreement by chance (both positive), EP+

$$EP+ = \{(a + b)/n\} \times \{(a + c)/n\}$$

Formula 6.3 Expected proportion agreement by chance (both negative), EP-

$$EP- = \{(c + d)/n\} \times \{(b + d)/n\}$$

Thus

Formula 6.4 Expected proportion agreement by chance, EP

$$EP = (EP+) + (EP-)$$

Formula 6.5 Observed agreement beyond chance, OA

$$OA = OP - EP$$

Formula 6.6 Maximum possible agreement beyond chance, MA

$$MA = 1 - EP$$

Then finally,

Formula 6.7 The ratio of the observed agreement beyond chance to the maximum possible agreement beyond chance, *kappa*

$$kappa = OA / MA$$

Also, 95% confidence interval of *kappa* statistics was calculated using Win Episcope (Thrusfield *et al*. 2001).

6.2.6.2. Prevalence of brucellosis

True prevalence of brucellosis was calculated both at herd level and animal level using the following formulae with data from both of BPAT and CELISA.

BPAT

The true prevalence of brucellosis was calculated using Formulae given in 6.8 (Rogan 1978; Thrusfield 2005) with the sensitivity and specificity of BPAT, 0.954 and 0.977. The confidence interval was calculated using Formula 6.9 (Thrusfield 2005).

Formula 6.8 A corrected true prevalence estimated using an imperfect test

$$P = \frac{P^T + \text{specificity} - 1}{\text{sensitivity} + \text{specificity} - 1}$$

where P^T is the test prevalence.

Formula 6.9 An approximate 95% confidence interval for the true prevalence

$$P - 1.96\sqrt{\text{var}\,P}, \quad P + 1.96\sqrt{\text{var}\,P}$$

where: var P = the variance of the true prevalence

$$= \frac{P^T(1 - P^T)}{n(Se + Sp - 1)^2}$$

where n = sample size, Se = sensitivity, Sp = specificity.

CELISA

Estimated prevalence was regarded as the true prevalence because sensitivity and specificity of CELISA were 1.000 and 0.999 respectively (Portanti 2006). The confidence interval was calculated using Formula 6.10 (Thrusfield 2005).

Formula 6.10 A confidence interval for proportionally allocated stratified random samples

$$P - 1.96 \sqrt{\frac{P(1-P)}{n}} \quad , \quad P + 1.96 \sqrt{\frac{P(1-P)}{n}}$$

where P = estimated prevalence, f = sample fraction, n = sample size

Power of the study: Type II error was calculated using Win Episcope 2.0 (Thrusfield *et al.* 2001). In the calculation, the number of total herds listed by LC1 leaders, estimated prevalence in CELISA, and the number of sampled herds were used. Level of confidence (100 - Type I error) was selected as 95%.

6.2.6.3. Herd size

The geometric mean (Crawley 2002) was used to calculate the mean herd (farm) size using statistical software R 2.4.1 because there were some outliers and that the error structures were not normally distributed. Commands used in R 2.4.1. are shown in Box 6.4.

Box 6.4 R commands for geometric mean

```
> geometric<-function(x)exp(sum(log(x))/length(x))
> geometric(x)
```

6.2.6.4. Within herd prevalence

Within herd prevalence was calculated using a Generalised Linear Model (GLM) with binomial errors using statistical software R 2.4.1 (R-commands are shown in Box 6.5). The 95% confidence interval of the logit: log (p/(1-p)) was calculated using Formula 6.11 (Crawley 2007), then transformed into a proportional scale using exponential in R 2.4.1 (Box 6.6).

<div style="border:1px solid black; padding:10px;">

Box 6.5 R commands for a Generalised Linear Model

1. Generalised Linear Model
> p<-Positive/Sample
> plot(Sample,p)
> y<-cbind(Positive,Sample-Positive)
> model<-glm(y~Sample,binomial,data=farms)
##Then obtain the exponential of intercept ##
2. An example of 95% confidence interval calculation
> exp(-3.87843-(qt(.975,176)*0.39241))
> exp(-3.87843+(qt(.975,176)*0.39241))

</div>

Formula 6.11   95% confidence interval of logit, CI (Crawley 2007)

$$CI = t_{a/2, df} * se, \qquad (t_{a/2, df} \text{ is the t-value in the table})$$

The relationship between within herd prevalence and herd size (both number of cows per farm and number of total animals - calves, heifers, cows, and bulls - per farm) was analysed using above GLM with binomial errors with R 2.4.1 (Box 6.6). Figures of frequency of herds with herd size were produced using R 2.4.1 (R-commands were shown in Box 6.6).

Box 6.6 R commands for a graph production of a GLM

```
> x<-seq(1,25,0.1)
> length(x)
[1] 241
> ypre<-predict(model,list(Sample=x),type="response")
> lines(x,ypre)
> plot(Sample,p,pch=16,cex=1.3,axes=FALSE,xlab="Number of cows in a
herd",ylab="Proportion of brucellosis positive cows",xlim=c(0,25),ylim=c(0,0.6),
frame.plot=TRUE)
> axis(side=2)
> axis(side=1,at=c(5,10,15,20,25),lab=c(5,10,15,20,25))
> lines(x,ypre)
```

6.2.6.5. Risk factors for brucellosis at the animal level

For univariate analysis, odds ratios were calculated for use of bull for insemination, vaccination, and abortion using Formula 6.12 (Thrusfield 2005). Confidence intervals were calculated using logarithmic-based methods shown in Formula 6.13 and 6.14 (Thrusfield 2005; Woolf 1955). The calculations were done manually using statistical software R 2.4.1

Formula 6.12   The exposure odds ratio: OR

$$OR = \frac{(a \times d)}{(b \times c)}$$

When a, b, c, d are categorised as in Table 6.2.

Table. 6.2 Relationship between risk exposure and the disease

	CELISA positive	CELISA negative
Exposure +	a	b
Exposure -	c	d

Formula 6.13   The variance of log OR: var

$$\text{var} = \frac{1}{a} + \frac{1}{b} + \frac{1}{c} + \frac{1}{d}$$

Formula 6.14   The confidence intervals (95%): CI

$$CI = OR \times \exp(-1.96\sqrt{\text{var}}), OR \times \exp(+1.96\sqrt{\text{var}})$$

Body condition score was compared between CELISA positive and negative cows using Kruskal-Wallis Rank Sum Test with MINITAB 15. Mean numbers of births and mean age was compared between CELISA positive and negative cows using a One-Way ANOVA after log-transformation with R 2.4.1. Boxcox transformation (Box 1964) statistic was used to calculate the transformation parameter λ (lambda). Log transformation was used because lambda was close to zero.

6.2.6.6. Risk factors for brucellosis at the herd level

Formulae 6.12, 6.13 and 6.14 were used for level of urbanicity (urban, peri-urban and rural), farming style (free range and restricted farming), cattle breed, insemination (use of artificial insemination (AI) or bull), vaccination, history of abortion and bought-in sampled cows, and existence of family member or cattle keeper with persistent fever. For categorical data, when exposure odds ratios were

calculated, the other categories were classified into non-exposure group. For example, when exposure to farming in urban areas was tested, farming in peri-urban and rural areas was added up as non-exposure to farming in urban areas for purpose of the calculation.

Significant risk factors found in univariate analysis was tested for interaction and confounding using stratified univariate analysis, the Mantel-Haenszel procedure (Mantel 1959; Thrusfield 2005) with Epi Info version 3.5.1 (CDC 2008) and when confounding was present, adjusted odds ratio was selected to report the result. When confounding was not present, crude odds ratio was selected.

6.2.6.7. Spatial epidemiology of brucellosis

During cattle sampling, the locations of sampled cattle farm were recorded with a hand-held Global Positioning System (GPS, Garmin, Olathe, KS, USA). The location of Kampala City centroid, Nakasero, was recorded in a previous survey (see Chapter 2). The National Biomass Study, from which the spatial data layers were obtained, is provided in the Universal Transverse Mercator (UTM) projection, with the detailed parameters as shown in Box 2.2 in Chapter 2 Section 2.2.5. GPS data were collected in latitude/longitude format, in the WGS 84 datum, and were converted for the Biomass projection for processing of maps using ArcView 3.1 Geographic Information System (ESRI Systems, Redlands, CA, USA). ArcGIS9 (ESRI Systems, Redlands, CA, USA) was used to produce the map.

Herd prevalence was compared among Districts and among Sub-counties using Generalised Linear Models (GLM) with binomial errors using the statistical software

R 2.4.1. The likelihood of having brucellosis positive herds was compared between northern Sub-counties located north of the city centroid, and southern Sub-counties using Fisher's Exact Test using statistic software R 2.4.1.

6.2.6.8. Quantity of infected milk produced daily in and around Kampala

Farmers were asked the average milk yield per day at the time of interview, not of the exact day of interview, in order to minimise uncertainty of daily variation. Uganda has a bimodal rainfall pattern with two dry seasons, one at mid-year which is short and uncertain, and one at the end of year which is longer and more pronounced. The rainy seasons are therefore, January to June, and July to December (Manning 1956). Since the interviews were conducted during October and November in 2007, the quantity of milk yielding in this study needs to be regarded as rainy season data. Regardless of the potential lactating performance of the cow, milk yield was recorded as zero when the cow was in a dry period, so that the data represent field conditions.

To calculate the quantity of *Brucella* infected milk produced at a CELISA positive farm, the milk yields from both CELISA positive and negative cows were added together as the milk produced both by positive and negative cows are usually mixed at the farm before selling.

Cross sum in the query function of Microsoft Access 2003 (Microsoft Office XP, Redmond, USA) was used to obtain the quantity of milk production per day by CELISA positive and negative farms in each farming category (small scale and large scale, improved, cross and indigenous breed cattle herd) and at each level of urbanicity. The quantity of milk sales to urban areas was also calculated in the same

manner.

Total quantity of infected and non-infected milk produced by the target cattle population per day, i.e. all cows in the studied 56 LC1s in the selected 10 LC3s (Section 6.2.1), was calculated by multiplying milk yields at the sample farms by the reciprocal of sample fractions (number of sample herds / number of total herds) in each category. Since stratified random sampling was used for the LC1 selection (see Chapter 2), these milk yields at the sample farms are representative of the milk yields by the target cattle population.

Finally, the quantity of infected and non-infected milk produced per day by the external cattle population, i.e. all cows in whole areas of the 10 LC3s in and around Kampala, was calculated by multiplying the quantity of milk production in the target population by the reciprocal of sample fraction of LC1 selection (87 out of 790 LC1s, chapter 2). Since LC1s and sampled farms were randomly selected, quantity of milk production in the sampled farms represents production from 10 LC3s in and around Kampala.

Information on the mode of milk sales was also recorded in relation to the quantity of milk production, so that the description on the distribution of infected milk with *Brucella* reflected the field situation.

6.3. Results

6.3.1. Sampled primary and secondary sampling units

In total, 425 secondary sampling units (cows) in 177 out of 625 primary sampling units (cattle herds) were sampled; the sample fraction at herd level was 28.3% (177/625).

Initially, the sample size of cattle herds was calculated as 289 out of a total of 1,202 total herds; this information was obtained from interviewing with LC1 leaders in the Village Characteristic Survey (VCS, details are in Chapter 2 and 3). The sample fraction was thus 24% (289/1,202). However, during October and November 2007, LC1 leaders listed only 625 cattle farms which had milking cows. Since LC1 leaders walked through their LC1s for sensitization and listed the names of cattle farmers at this time, this number is probably more accurate than those from the VCS.

In Chapter 3, the total number of cattle farms was reported as 1,039 when all categories were added up (Chapter 3, Section 3.3.2.2, Table 3.8); this number is smaller than the total number of cattle herds obtained in the VCS - 1,202. This difference resulted from possible exaggerations of the number of cattle farms in two of the peri-urban LC1s in the VCS interviews that were corrected to reduce this known bias.

There were a few farmers who refused to be interviewed. Such 'refused' farms were substituted with another farm in the same category using the same random selection procedure previously described. However when there was no alternative farm, the category was left unfilled.

6.3.2. Agreement between BPAT and CELISA

Out of 423 samples, 185 cows were positive in BPAT, and 21 cows were positive in CELISA (Table 6.3). The agreement of two tests, *kappa* value was 0.083 (95% CI: 0.037-0.130) and it showed poor agreement. Four samples were detected in CELISA only, which is probably due to the greater sensitivity of the CELISA test. A large proportion of BPAT positives were false positives, i.e. diagnosed as negative using CELISA (168/185, 90.8%). Since 17.9% (30/168) of cows were vaccinated against brucellosis, 82.1% (138/168) of the false positives might be due to cross reactions with other micro-organisms. Due to the poor agreement between BPAT and CELISA, the present study uses the results only from CELISA for the analysis.

Table. 6.3 Relationship between BPAT and CELISA results

	CELISA positive	CELISA negative	Total
BPAT positive	17	168	185
BPAT negative	4	234	238
Total	21	402	423

6.3.3. Prevalence of brucellosis at animal level

The true prevalence of brucellosis in BPAT was calculated as 44.5% (95% CI: 39.4 – 49.5). However, only 21 out of the 423 sampled cows were positive when CELISA was used. The prevalence at animal level was 5.0% (95% CI: 2.9 – 7.0) using CELISA.

6.3.4. Prevalence of brucellosis at herd level

Out of 177 sampled herds, 93 were positive using BPAT; herd prevalence of brucellosis was 52.5%. True prevalence was 56.4% (95% CI: 48.6 – 64.2), which was very close to the expected prevalence, 55.6%.

However, when the CELISA test was used, the prevalence was very different from the BPAT result. Out of 177 sampled herds, 11 herds were positive, and the herd prevalence of brucellosis was 6.2% (95% CI: 2.7-9.8) with the CELISA test.

6.3.5. Power analysis

As mentioned above, the total number of cattle farms keeping milking cows in the target population, 625, was far smaller than the number of cattle farms, 1,202, obtained from VCS. Also, the prevalence of brucellosis using CELISA was significantly lower than the prevalence using BPAT. Therefore, power of this study was analysed using Type II error which was calculated as 3.01% (exact error). The power of the study was calculated as 96.99% (100 – 3.01).

6.3.6. Herd size

Fig 6.2 shows the frequency of herds according to the number of milking cows in a herd. The geometric mean of number of cows per farm was 1.659. Fig 6.3 shows the frequency of herds according to the number of total animals including calves, heifers, cows, bulls, and oxen in and around Kampala. The geometric mean of number of animals was 3.339.

Herd size
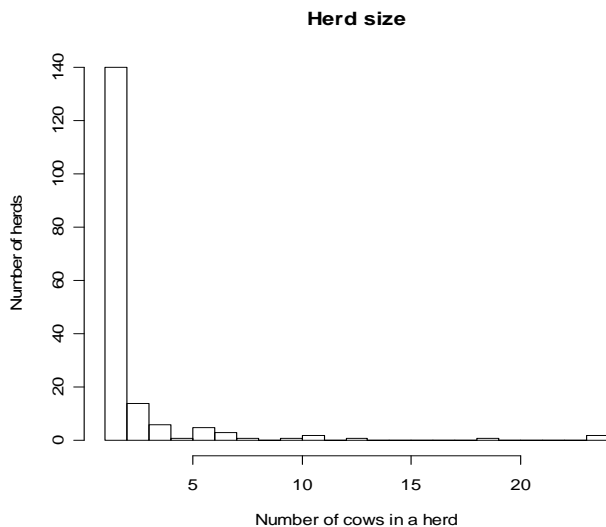
Fig. 6.2 The number of herds according to the number of milking cows in a herd

Herd size
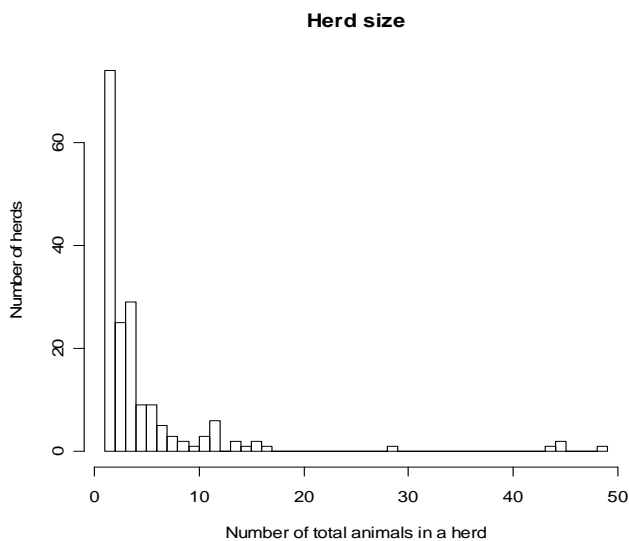
Fig. 6.3 The number of herds according to the number of animals in a herd

6.3.7. Within herd prevalence

Fig 6.4 shows box-and-whisker plots of the proportions of brucellosis positive cows according to the number of cows in a herd. Within herd prevalence of brucellosis varied between 0 to 50.0%, and the overall mean within-herd prevalence was 2.0% (95% CI: 0.1 - 4.5). Most of the herds with less than 10 cows in a herd did not have brucellosis positive cows and larger herds had higher within-herd prevalence. The logit of within herd prevalence of brucellosis increased linearly with the number of milking cows in a herd (slope=0.094, se=0.02, $p<0.001$, fitted line was not shown in Fig 6.4).
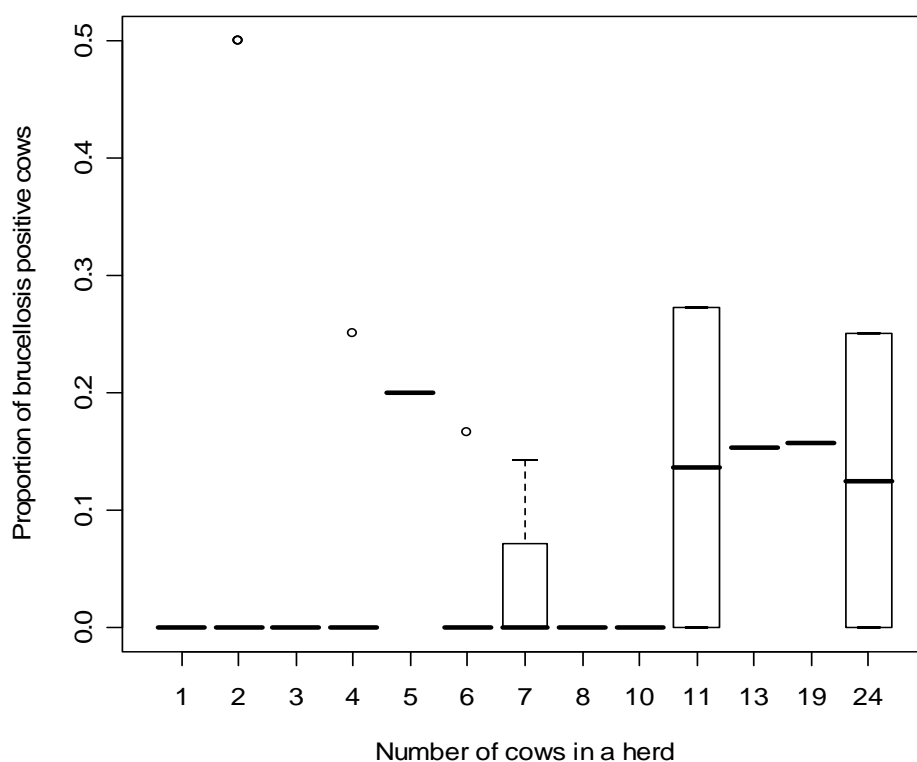
Fig. 6.4 Box and whisker plot of the proportions of brucellosis positive cows according to the number of cows in a herd. Horizontal lines show the median, 25th and 75th percentiles. The vertical dashed line at 7 cows in a herd shows the maximum proportion.

6.3.8. Risk factors for brucellosis at the animal level

In the univariate analysis, use of a bull for insemination, vaccination and abortion were not significant risk nor preventive factors for brucellosis infections at the animal level; all of the 95% confidence intervals of odds ratios included 1 (Table 6.4).

Table. 6.4 Univariate analysis of risk factors for brucellosis at animal level

Factors	Diseased	Healthy	Odds ratio (95% CI)
Use of bull for insemination			1.78 (0.51 – 6.18)
Bull	18	310	
AI	3	92	
Vaccination			1.78 (0.63 – 5.04)
Vaccinated	5	60	
Not vaccinated	16	342	
Abortion			1.43 (0.40 – 5.05)
Aborted	3	42	
Not aborted	18	360	

Mean rank of body condition score was not significantly different between CELISA positive (median=3.0, average rank=218.2) and negative cows (median=3.0, average rank=211.7, df=1, p=0.799). Mean number of births was not significantly different between CELISA positive (2.76, 95%CI: 2.06 – 3.69) and negative cows (2.39, 95%CI: 2.24 – 2.56, p=0.341). Mean age was also not significantly different between CELISA positive (5.53, 95%CI: 4.76 – 6.44) and negative cows (5.20, 95% CI: 5.03 – 5.38, p=0.420). No significant risk factor for brucellosis could be detected at the animal level, and multivariate analysis was not performed.

6.3.9. Risk factors for brucellosis at the herd level

6.3.9.1. Univariate analysis

Univariate analysis at the herd level identified three significant risk factors for brucellosis (Table 6.5a, 6.5b):

  1. Large herd size (odds ratio (OR): 20.38, 95% CI: 2.93 – 141.55),

  2. Free range farming (OR: 9.42, 95% CI: 2.57 – 34.50)

  3. History of abortion (OR: 3.95, 95% CI: 1.06 – 19.40)

While free movement of cattle are associated with brucellosis, 4 out of 134 movement-restricted herds were infected with brucellosis (3 out of 57 zero grazed herds and one out of 66 herds tied in public land were infected, and none of 14 herds tied in own land were infected). The level of urbanicity, cattle breed, use of a bull for insemination, vaccination, bought in cattle, and existence of patients with persisting fever among family or herdsmen were not significant risk factors.

Table. 6.5a Univariate analysis for risk factors for brucellosis at the herd level

Factors	Diseased	Healthy	Odds ratio (95% CI)
Urbanicity			
Urban	4	50	1.33 (0.37 – 4.73)
Peri-urban	2	47	0.56 (0.12 – 2.70)
Rural	5	69	1.17 (0.34 – 3.99)
Herd size			20.38 (2.93 – 141.55)*
Large (cows>=10)	3	3	
Small (cows<10)	8	163	

Table 6.5b Univariate analysis for risk factors for brucellosis at the herd level

Factors	Diseased	Healthy	Odds ratio (95% CI)
Free range farming			9.42 (2.57 – 34.50)*
Free range	7	26	
Restricted	4	140	
Breed			
Improved	4	57	1.09 (0.11 – 11.3)
Cross	3	61	0.65 (0.16 – 2.52)
Indigenous	4	48	1.41 (0.39 – 5.02)
Use of bull for insemination			0.99 (0.25 – 3.91)
Bull	8	121	
AI	3	45	
Vaccination			5.05 (0.91 – 27.87)
Vaccinated	2	7	
Not vaccinated	9	159	
Abortion			3.95 (1.06 – 19.40)*
Aborted	4	21	
Not aborted	7	145	
Bought-in cattle			0.78 (0.19 – 3.18)
Yes	7	119	
No	3	40	
Persistent fever patients			0.94 (0.11 – 7.81)
Exist	1	16	
Not exist	10	150	

6.3.9.2. Stratified univariate analysis

Three risk factors for brucellosis at the herd level: large herd size, free range farming and history of abortion were identified by the univariate analysis as explained in the previous section. Free range farming may enhance the chance of contacts with the highly contaminated fluids and tissues with *Brucella* expelled on abortions. However, being large herd is not biologically related with brucellosis. Therefore, stratified univariate analysis was performed using Mantel-Haenszel procedure (Mantel 1959) to control the confounding.

Table 6.6 shows the stratified univariate analysis for farming style with stratification by herd size. Although Woolf's statistic (Woolf 1955) was not able to calculate due to the absence of infected large scale herds keeping cattle restricted, by observation from Table 6.6, strata were not homogeneous and large scale farms were more likely to keep cattle free range than small herds. The 29.1% change from the crude odds ratio to the adjusted odds ratio ((crude OR - adjusted OR)/crude OR) suggested moderate to serious confounding by the large herd size was present (as a rule of thumb increase of odds ratio greater than 30% suggests the presence of serious confounding (Dohoo 2004)). Adjusted odds ratio was 6.68 (95%CI: 1.60 – 27.90) and free range farming was a risk factor for brucellosis at the herd level.

Table. 6.6 Stratified univariate analysis of the relationship between brucellosis and farming style with stratification by herd size using the Mantel-Haenszel procedure (Mantel and Haenszel, 1959)

Herd size	Farming style	Diseased	Healthy	Total
Large	Free range	3	2	5
Large	Restricted	0	1	1
Sub-total		3	3	6
Small	Free range	4	24	28
Small	Restricted	4	139	143
Sub-total		8	163	171
Total		11	166	177

Odds ratio (large herd) = undefined

Odds ratio (small herd) = 5.79 (95%CI: 1.36-24.74)

Crude odds ratio = 9.42 (95%CI: 2.57 – 34.50)

Adjusted odds ratio = 6.68 (95%CI: 1.60 – 27.90)

As the next step, since abortion might be related with free range farming, the stratified univariate analysis for history of abortion with stratification by farming style was performed (Table 6.7). The change of crude to adjusted odds ratio was by 8.6% and serious confounding by farming style was not present. Thus crude odds ratio (3.95, 95%CI: 1.06 – 19.40) was chosen and although the lower limit was close to 1, history of abortion was also a risk factor of brucellosis at the herd level.

Table. 6.7 Stratified univariate analysis of the relationship between brucellosis and history of abortion with stratification by farming style using the Mantel-Haenszel procedure (Mantel and Haenszel, 1959)

Farming style	Abortion	Diseased	Healthy	Total
Free range	Aborted	2	4	6
Restricted	Not aborted	5	22	27
Sub-total		7	26	33
Free range	Aborted	2	17	19
Restricted	Not aborted	2	123	125
Sub-total		4	140	144
Total		11	166	177

Odds ratio (free range) = 2.20 (95%CI: 0.31 – 15.55)

Odds ratio (restricted) = 7.24 (95%CI: 0.96 – 54.79)

Crude odds ratio = 3.95 (95%CI: 1.06 – 19.40)

Adjusted odds ratio = 3.61 (95%CI: 0.89 – 14.68)

6.3.10. Spatial epidemiology of brucellosis positive herds

Fig 6.5 shows the spatial distributions of brucellosis positive and negative farms. While brucellosis negative herds were well scattered in and around Kampala, positive herds were restricted to northern areas of the Kampala economic zone (Kawempe, Wakiso, Kira, Nabuweru, Nangabo, and Goma Sub-counties).
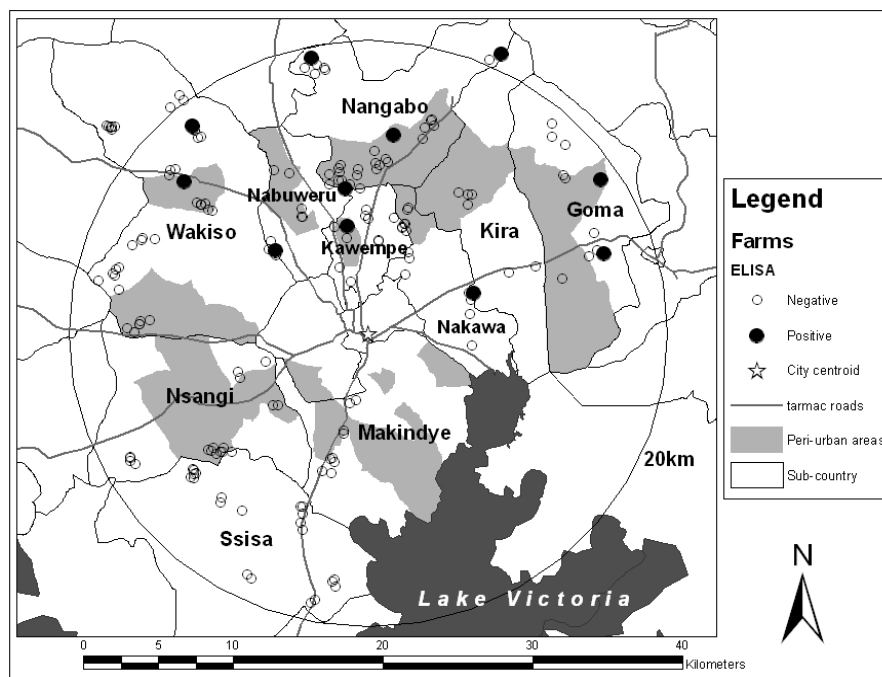
Fig. 6.5 Spatial distributions of brucellosis positive farms: black points represent farms with positive cows while hollow circles represent farms without positive cows

Although herd prevalence of brucellosis was not significantly different among districts ($p=0.352$), nor Sub-counties ($p=0.257$, Table 6.8), northern Sub-counties (Kawempe, Nakawa, Wakiso, Wakiso Town Council, Kira, Nabuweru, Nangabo and Goma) were more likely to contain positive herds (11/ 130 herds) than southern Sub-counties (Nsangi, Ssisa and Makindye, 0/ 47 herds, odds ratio=0, 95% CI: 0.0-1.06, $p=0.038$) and cattle farming took place more in north than south.

Table. 6.8 Brucellosis herd prevalence in Districts and Sub-counties

	Positive	n	Prevarence (95% CI)	p-value
Districts				*p*=0.352
Kampala	1	23	4.3 (0.2 – 24.0)	
Wakiso	8	143	5.6 (2.6 – 11.1)	
Mukono	2	11	18.2 (3.2 – 52.2)	
Sub-counties				*p*=0.257
Kawempe	1	11	9.1 (0.5 – 42.9)	
Nakawa	0	12	0.0 (0.0 – 30.1)	
Nsangi	0	17	0.0 (0.0 – 22.9)	
Ssisa	0	21	0.0 (0.0 – 19.2)	
Wakiso	2	36	5.6 (1.0 – 20.0)	
Wakiso Town Cowncil	0	7	0.0 (0.0 – 43.9)	
Kira	1	9	11.1 (0.6 – 49.3)	
Makindye	0	9	0.0 (0.0 – 37.1)	
Nabuweru	1	10	10.0 (0.5 – 45.9)	
Nangabo	4	34	11.8 (3.8 – 28.4)	
Goma	2	11	18.2 (3.2 – 52.2)	

The majority of herds with the risk factors identified in the previous section, free range farming and history of abortion, were located in the northern districts but some were in the southern districts (Fig 6.6 and Fig 6.7).
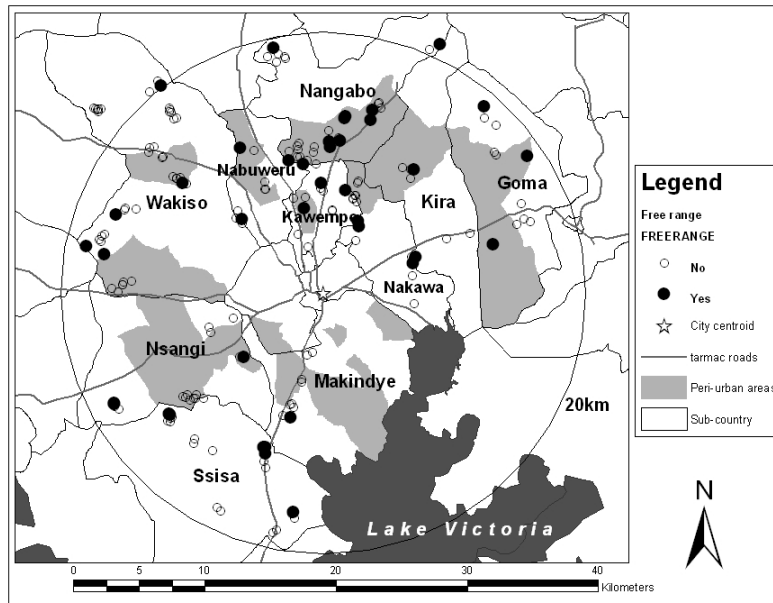
Fig. 6.6 Spatial distributions of free range farms: Black points represent large size farms while hollow circles represent small scale farms
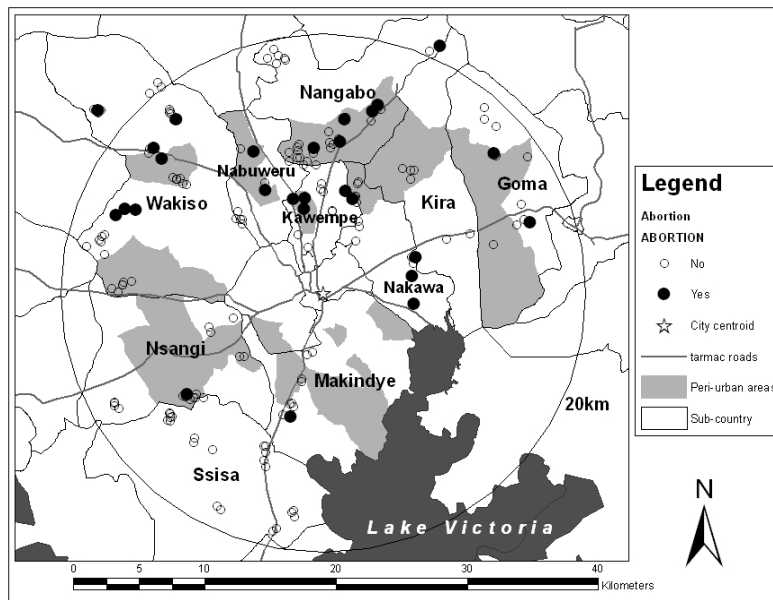
Fig. 6.7 Spatial distributions of farms with history of abortion: Black points represent farms with history of abortion while hollow circles represent farms without abortion

The large size herds were located only in the northern parts (Fig 6.8). Five out of 6 large size herds kept cattle free range and 3 of them were infected with *B. abortus* (see Table 6.6 in section 6.3.9.2).
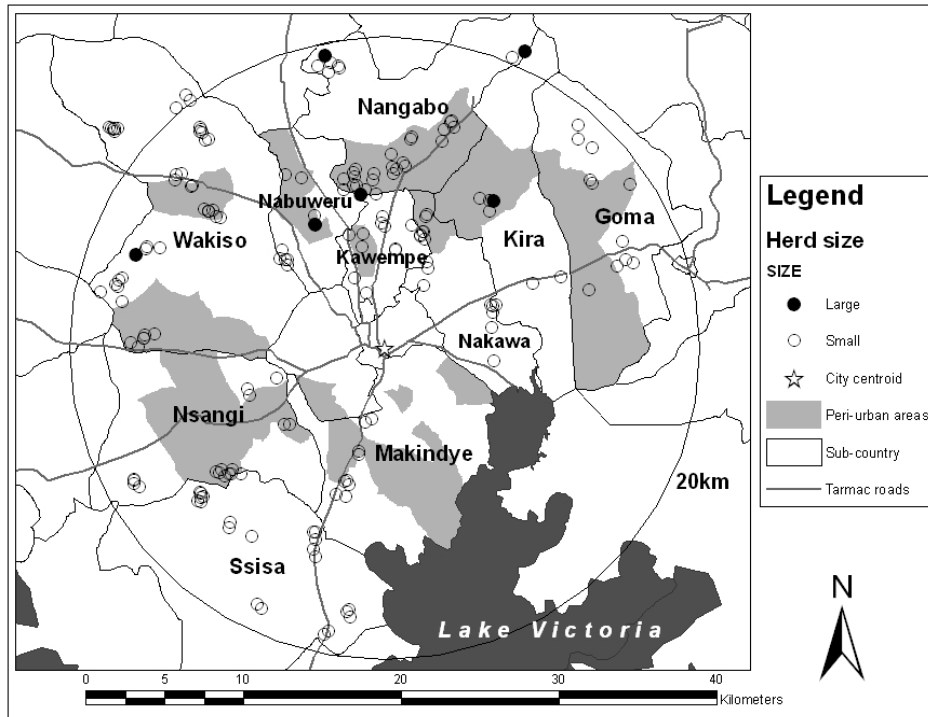
Fig. 6.8 Spatial distributions of large size farms: Black points represent large size farms while hollow circles represent small scale farms

6.3.11. Quantity of infected milk produced in and around Kampala a day

Table 6.9 shows the estimated quantity of milk production in and around Kampala per day. Out of 92,899 litres of milk produced in and around Kampala, 43,636 litres (47.0%) were distributed to urban households mainly by milk distributors using bicycle (destination of marketed milk: urban areas, in Table 6.9). These milk distributors purchase milk at the farm gate and were selling to contracted individual households, fresh milk shops and any customer who stops them on the way to their contracted customers.

In urban areas where a large number of human brucellosis cases were found, 4,566 litres of milk infected with brucellosis was produced and consumed locally (either home consumption of dairy farmers or direct purchase at the farm gate), and 11,737 litres of infected milk was transported from peri-urban and rural areas each day. In total, 18.6% (17,235 out of 92,899 litres) of milk produced in and around Kampala was estimated to be infected with *Brucella*.

Table. 6.9 Quantity of milk produced in and around Kampala (L/ day)

Destination of marketed milk	CELISA	Quantity of milk production (L/ day)			Total
		Urban	Peri-urban	Rural	
Urban areas	Positive	0	2,929	8,808	11,737
	Negative	4,209	17,424	10,266	31,899
Local	Positive	4,566	0	932	5,498
consumption	Negative	16,454	12,085	15,226	43,765
Total		25,229	32,438	35,232	92,899

6.4. Discussion

During cattle sampling in the field, a large difference was found between the number of total herds obtained from interviews with LC1 leaders in the VCS carried in 2005 (1,202), and the number of cattle herds with milking cows listed by the LC1 leaders prior to cattle sampling in 2007 (625). Since LC1 leaders walked through their LC1s for sensitization and listed the names of cattle farmers at this time, their estimate number is probably more accurate than numbers form the previously conducted VCS. This very large disparity may be attributed to three factors:

1. Large numbers of non-cow keeping cattle farms.

   There were two types of non-cow keeping cattle farms: the farms keeping only bulls (for cultivation or sales as beef cattle) and farms with pregnant heifers after selling their cows.

2. Rapid decrease of cattle farms in urban and peri-urban areas.

   Since 2005 when the VCS was conducted, cattle farming had ceased in 2 out of 56 LC1s by 2007. A SVO in peri-urban area found that the number of cattle farms was rapidly decreasing with the progress of urbanization.

3. Bias from the interviews to LC1 leaders.

   LC1 leaders had to answer questions without having had time to count the number of cattle farm in VCS. Also, there were some significant exaggerations of the numbers by LC1 leaders. Exaggeration may be due to expectation of benefits for LC1s from responding to questions positively (personal communications from SVOs).

Fortunately, as the analysis had enough power and as the random sampling of cattle herds with milking cows was conducted rigorously, the calculated prevalence is robust.

The agreement between BPAT and CELISA results was poor and the present study used only CELISA results for the analysis. A large proportion of BPAT positives were false positives (168/185, 90.8%) and as 17.9% (30/168) of cows were vaccinated against brucellosis, 82.1% (138/168) of the false positives might be due to cross reactions to the microorganisms. It must be noted that any slight sign of agglutination was diagnosed as positive on the BPAT, and this might be responsible for a large part of the false positives. In field trials of CELISA in Latin America, the percentage of false positive serum reactions among positive sera on both the RBT and CFT was: 0% (0/692 cattle) in Chile, 1.88% (5/266) in Colombia and 6.84% (13/190) in Costa Rica (Gall 1998). However, since CFT is a confirmatory test (OIE 2008), those sera which were positive on the RBT and negative on the CFT, i.e. false positive serum reactions (FPSR), would have been expected. Nevertheless, such sera were not tested in these Latin American studies and the total proportions of FPSR were not given. Studies on brucellosis in cattle in Sub-Saharan Africa were reviewed in detail by McDermott & Arimi (2002). There are no published studies comparing the results from CELISA with RBT or BPAT in Africa. The present study suggests that a large number of FPSR for brucellosis can arise in the field in Uganda. Several studies have been carried out on the prevalence of brucellosis in cattle in Uganda since 1972 (Newton *et al.* 1974). Since then, it is generally accepted that the high plateau lands of western and eastern Uganda remain zones of hyper-endemicity, and the central and southern part of the country along the shore of Lake Victoria remain zones of moderate endemicity both of human and bovine brucellosis (Ndyabahinduka & Chu 1984). A study in the central and southern parts of Uganda (one farm in Kampala, 5 in Mukono and 10 in Wakiso) reported high prevalence of

brucellosis at the herd level (56.3%, 9/16) and at animal level, 5.0% (19/383) using both RBT and serum agglutination test (SAT) (Nakavuma 1994). More recently, in urban and peri-urban areas of Kampala, 42% (102/245) of the cattle serum samples were positive for antibodies against *Brucella* using slow serum tube agglutination test (Mwiine 2004). However, as SAT is less specific than CFT and CELISA (OIE 2008), this high prevalence at the herd level might be due to false positive reactions. A most recently published study using RBT found a herd prevalence of brucellosis of 55.6% (95% confidential intervals 50, 61.2) out of 315 herds and an individual animal prevalence of 15.8% (14.8, 16.7) out of 12,764 heads in Mbarara District, which is the most important dairy production areas in Uganda (Bernard *et al.* 2005). Considering the large proportion of FPSR in the field of Uganda which the present study revealed, the herd and animal prevalence of brucellosis in Mbarara may have been lower. In the present study, the herd prevalence of brucellosis was 6.2% (95% CI: 2.7-9.8), and individual animal prevalence was 5.0% (95% CI: 2.9 – 7.0) in urban and peri-urban areas of the Kampala economic zone using CELISA. These results indicate that future studies of brucellosis in Uganda should use the CELISA tests as a confirmatory test.

The present study identified two risk factors for brucellosis at the herd level: free range farming and history of abortion after controlling the confounder: herd size. Abortion was associated with brucellosis without interaction with the free range style of farming. Brucellosis is reported to spread between herds largely through the cattle movement or by contact at pasture, with associated risk factors including size, type and density of herds (Abernethy 2006; Kellar 1976; Salman 1984; Sheahan 2002). However in the present study, bought-in history of cattle was not a risk factor for

brucellosis; it suggested the endemic status of brucellosis in and around Kampala might be maintained indefinitely although at a low herd prevalence. Also in the present study, a few zero-grazing herds were also found to be infected with brucellosis which may have been to purchasing infected animals and/or using contaminated frozen semen, or infected bulls. As use of bulls was shown not to be a risk factor, contamination of frozen semen with *Brucella* could not be ruled out. Level of urbanicity was not a risk factor for brucellosis in Kampala. More generally in Africa, a higher prevalence of brucellosis has been reported in intensive systems in Eritrea (Omer 2000), in humid areas in Côte d'Ivoire, Nigeria and Burkina Faso (Gidel 1976), and in exotic breeds in Mbarara, Uganda (Bernard 2005). However exotic cattle breed was not a risk factor in the present study.

Spatial epidemiology indicated farming in northern part of the Kampala economic zone being a spatial risk factor although the association was not so strong. There were more herds with the identified risk factors: free range farming and history of abortion, in north than south. All the large size herds of which a half of them were infected with *B. abortus* were located in the northern part. In southern part of the Kampala economic zone, with Lake Victoria to the southeast and the rapid urban development along the Entebbe Road, there might not be enough land available to operate cattle farming. However, infected milk produced in peri-urban and rural areas of the Kampala economic zone and the other larger dairy production areas is sold in whole urban areas, so the risk of purchasing infected milk is not restricted to the northern parts of Kampala.

Risk factors for brucellosis at the level of an individual animal were not identified in the present study. Age of animal has been shown to be a risk factor in other studies in Mbarara, Uganda (Bernard 2005) and in Northern Ireland (Abernethy 2006). While birth order and age were not identified as risk factors in the present study, this may be simply because all samples were taken from only milking cows which are usually more than 2 years old.

Surprisingly vaccination was not a preventive factor for brucellosis infection in the present study. S19 vaccine is known not to perfectly protect animals from *Brucella abortus* infection; reports of its efficacy have revealed great variation from 38% (n=29, (Bagnat 2002; Moriyon 2004) to 95% (n=22, (Cheville 1996). Vaccine strain RB51 is much more effective and completely protects animals both from infection and abortion (Cheville 1996). Moreover, strain RB51 does not induce antibodies which S19 induces and complicate the diagnostic tests for brucellosis, because RB 51 lacks O-polysaccharide but S19 has it (Moriyon 2004). Vaccine strain RB51 may be a far more useful tool to use in Uganda. Our study suggested that owners of large scale free range cattle farms and zero grazing farms should be encouraged to vaccinate animals against brucellosis using RB51.

This study revealed that a large quantity of milk infected with *Brucella* is produced in peri-urban and rural areas, especially northern parts of Kampala, and distributed to the urban areas of Kampala and consumed together with locally produced milk. In order to develop control strategies for human brucellosis in Kampala, it is necessary at first to deal with the market chain for untreated milk infected with *Brucella* and this was the purpose of this studies described in the following Chapter 7.

7. Chapter 7 Risk analysis for purchase of milk infected

with *Brucella abortus* in urban areas of Kampala

7.1. Introduction

7.1.1. Aims

The aims of this study were to:

1. Assess the daily risk of purchasing raw milk infected with *Brucella abortus* for populations living in urban areas of Kampala during the rainy season

   and

2. Identify the best options for control of human brucellosis in urban areas of Kampala.

7.1.2. Brucellosis in humans in Uganda

General information of brucellosis is described in the introduction of Chapter 4 and its prevalence in cattle in Uganda is in Chapter 6. Here, epidemiology of human brucellosis in Uganda is described.

As bovine brucellosis seems to be prevalent in the whole area of Uganda, human brucellosis cases may be seen in the whole country. Infection rate of milk with *Brucella* has been studied in urban and peri-urban areas of Kampala; 44.4% (72/162) of milk samples were positive using the Milk Ring Test (MRT) (Mwiine 2004). In the central and southern parts of Uganda which include urban and peri-urban Kampala (Wakiso and Mukono districts), 15.3% (19/124) of bulk milk samples were positive using the MRT (Nakavuma 1994). Human brucellosis was tested in combination with tests for bovine brucellosis by Ndyabahinduka and Chu (1984) and the percentage of positive agglutinin reactors among the unselected hospital patients in Karamoja, northeast Uganda was 24.4% and in Kabale, southwest Uganda was

18%. The high infection rate among the Karamoja people was due to their nomadic life style as pastoralists eat raw meat and milk.

At Mulago National Referral Hospital, 13.3% of patients who had general malaise or joint pain and/or constant headaches and for whom multiple tests were requested were diagnosed with brucellosis, while 73% were found to have malaria (Mutanda 1998). The symptoms and signs of brucellosis are highly variable and, though it is said to be rare, neurobrucellosis is also seen in Uganda. Kyebambe (2005) reported one case of acute brucella meningomyeloencephalo-spondylosis with early osteophyte formation on the vertebral foramina of a male teenager diagnosed at Kabale Regional Referral Hospital in Uganda. In another study, 17.2% of 204 patients in Mulago National Referral Hospital whose chief complaint was low back pain had serious spinal pathology due to tuberculosis as well as brucellosis, fractures and degenerative changes (Galukande *et al.* 2005).

7.1.3. Diagnostic tests of brucellosis in milk samples

OIE (2004) recommends two screening tests for brucellosis in bulk tanks: the milk indirect enzyme-linked immunosorbent assay (IELISA) and the milk ring test (MRT). MRT has been effective in locating infected herds in official control and eradication programmes on an area basis, but there are a high percentage of false positives (Merck Veterinary Manual. 2008). Agglutination tests such as buffered plate agglutination test (BPAT) and Rose-Bengal Test (RBT) may detect antibodies in milk (Merck Veterinary Manual. 2008). However, agglutination tests produce cross reactions against Enterobacteriaceae such as *Yersinia enterocolitica* 0:9 (Bundle 1984). Polymerase Chain Reaction (PCR) is also available for the detection of

Brucella in milk (Leal-Klevezas 1995); this is a highly sensitive test and offers detailed molecular information; however the numbers of brucellae in bulk milk samples are usually low, and even with PCR may not be detected (OIE 2004).

7.1.4. Sensitivity and specificity of milk IELISA

The milk IELISA is a sensitive and specific test and is particularly valuable for testing large herds. The milk ring test (MRT) is a suitable alternative if IELISA is not available; however false-positive reactions may occur in cattle vaccinated less than 4 months prior to testing or in samples containing abnormal milk (such as colostrum) or in cases of mastitis (OIE 2004). In Uganda, brucellosis vaccine is known to be used by farmers (Bernard *et al.* 2005) and false-positive reactions with MRT would be expected. The sensitivity and specificity of milk IELISA for *B. abortus* have been reported in a number of studies (see Table 7.1).

Table. 7.1 Reported sensitivity and specificity of milk IELISA for *Brucella abortus*

	Sensitivity	Specificity	Sample	Country
(Romero 1995)	98.2		56 cows (+)	Spain
		100	37 cows (-)	
(Nielsen 1996)	95.2		202 cows	Chile
	(91.5-98.9)			
	98.7			Argentina
	(98.4-99.0)			
		99.95	6440 cows	Canada
(Vanzini *et al.* 1998)	99.6	99.1	2119 cows	Argentina
	(98.6–99.9)	(98.9–99.4)		
(Vanzini 2001)	98.1	88.1	31 diluted milk	Argentina
(Rivera 2003)	95.3	95.1	1523 cows	Colombia
			200 bulk milk	
(Lavaroni 2004)	100	95	199 vaccinated cows	Argentina
(Nielsen 2004)	98.5	99.9	4250 cows	Canada

+: *Brucella abortus* **was cultured. -: not cultured.**

7.1.5. Risk analysis

Risk analysis has been defined as 'a detailed examination including risk assessment, risk evaluation, and risk management alternatives, performed to understand the nature of unwanted, negative consequences to human life, health property, or the environment; an analytical process to provide information regarding undesirable events; the process of quantification of the probabilities and expected consequences for identified risks' (Society for Risk Analysis. 2008). Risk analysis has been applied to a variety of subjects, for example: food safety (Nauta 2007), animal health and trade (Hartnett 2007), public health (Dowdle 2006), environmental impact (Snary 2002), agriculture (Ibitayo 2006), engineering (Mazzola 2000), financial management (Kunreuther 2003) and security against terrorism (Willis 2008).

There are two systems of risk analysis used in animal health, food safety, and veterinary public health: the OIE International Animal Health Code (OIE 2002) and the Codex Alimentarius Commission (Codex Alimentarius Commission 1999). The OIE International Animal Health Code system deals with the disease risks associated with the importation of animals, animal products, animal genetic material, feedstuffs, biological products and pathological material (OIE 2002), while the Codex Alimentarius Commission system estimates the risks from microbiological hazards in foods (Codex Alimentarius Commission 1999). The present study uses the latter system to estimate the risk from raw milk consumption.

Risk analysis in Codex Alimentarius Commission comprises three components: risk assessment, risk management and risk communication (Box 7.1) (Codex Alimentarius Commission 1999).

Box 7.1 Definitions for components of microbiological risk analysis
(Codex Alimentarius Commission 1999)

Risk assessment:

A scientifically based process consisting of the following steps: (i) hazard identification, (ii) hazard characterization, (iii) exposure assessment, and (iv) risk characterization.

Risk management:

The process of weighing policy alternatives in the light of the results of risk assessment and, if required, selecting and implementing appropriate control options, including regulatory measures.

Risk communication:

The interactive exchange of information and opinions concerning risk and risk management among risk assessors, risk managers, consumers and other interested parties.

7.1.6. Milk pasteurisation

Cow's milk is an exceptionally valuable food for the human species throughout the growth period; however, milk may be contaminated with pathogenic micro-organisms derived from cattle as well as from humans, water or rodents (Wilson 1942). The micro-organisms pathogenic to humans in raw milk derived from cattle include: *Mycobacterium bovis* which causes tuberculosis both to humans and cattle (Cleaveland *et al.* 2007); *B. abortus* which causes brucellosis; *Streptococcus pyogenes* which causes scarlet fever – septic sore throat (Eyler 1986; Wilson 1942); *Coxiella burneti* which causes Q fever (Guatteo 2007); *Escherichia coli* O 157 (Grace 2008) and *Salmonella* (Nero 2008) which cause gastro-enteritis; *Listeria monocytogenes* which causes listeriosis (Nero 2008).

All these organisms can be killed simply by pasteurization (FAO 1953). There are several types of pasteurization:

1) Flash pasteurization- momentary exposure to a temperature of 140-176˚F (60-80˚C) or even higher,

2) High temperature pasteurization – a few seconds at 176-185˚F (80-85˚C),

3) High temperature short time pasteurization – 15-20 seconds at 159.8-162˚F (71-72.2˚C) and

4) Low temperature pasteurization – 30 minutes at 138-150.8˚F (58.9-66˚C) (Wilson 1942).

7.1.7. Current dairy hygiene policy of the Dairy Development Authority, Uganda

In October 2007, the author was given a chance to attend a meeting organised by the Dairy Development Authority (DDA), in the Wakiso District Office to discuss dairy hygiene improvement in Uganda. The DDA is promoting the provision of cold chains for milk by constructing milk centres with a bulk cooler within Wakiso District that includes peri-urban areas of the Kampala economic zone in it. The Director of DDA also outlined a plan to ban the business of milk vendors/traders selling from bicycles within urban areas in Kampala.

The DDA has had a significant impact on dairy hygiene by the introduction of cooling trucks with large milk tanks transporting milk from dairy production areas such as Mbarara and Nakasongola to Kampala City since 2006. However, they did

not have a programme to promote the practice of boiling milk. The findings of the present study will be considered by the Director of DDA in planning control of milk borne zoonotic diseases in Kampala.

7.2. Materials and methods

7.2.1. Study sites

This study was conducted in the 48 LC1s randomly selected in urban areas of Kampala, the capital of Uganda (Fig 7.1). Initially 87 LC1s were selected in the Kampala economic zone for this series of studies (Chapter 2). Out of 87 LC1s selected, 59 LC1s were classified as urban based on the definition of levels of urbanisation and associated decision tree model. Finally, 48 out of 59 urban LC1s were selected for the present study because 7 LC1s were institutions/ universities and 4 LC1s were located in very high income residential areas where milk shops were not found. Further details were described in Chapter 2.
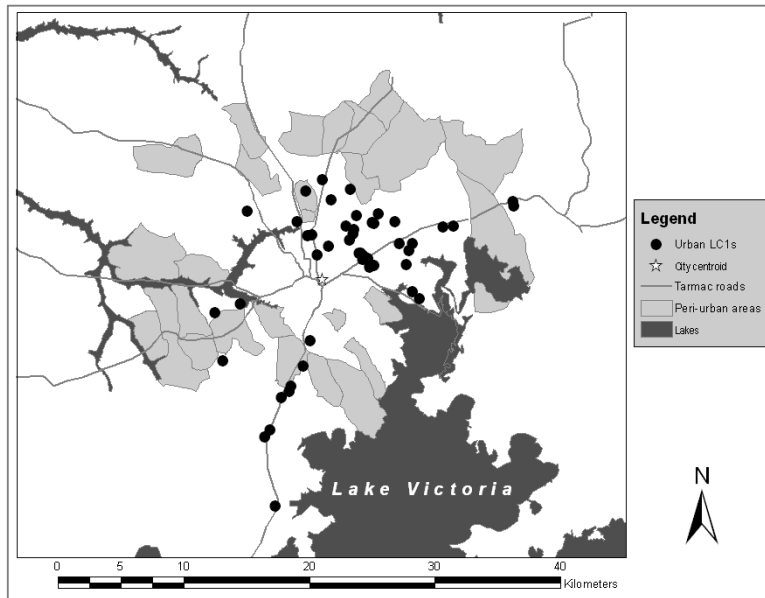
Fig. 7.1 Map of Kampala showing the locations of 48 urban LC1s studied. Areas highlighted are peri-urban parishes.

7.2.2. Study design

This study was designed to conduct a quantitative risk assessment for urban dwellers in Kampala of purchasing raw milk infected with *B. abortus* per day, using a

deterministic risk model and to determine the best control option to reduce the risk by simulation with the risk model.

Risk assessment is the quantifying, either qualitatively or quantitatively, of the probability and the potential impact of some risk (Vose 2000). A risk assessment proceeds from a qualitative description of the risk to a semi-quantitative or quantitative analysis, and a quantitative analysis can use either deterministic or stochastic modelling (Vose 2000). Stochastic modelling is preferable since by deterministic modelling, single point estimates of risk are obtained as risk outputs whilst by stochastic modelling, probability distributions are obtained as outputs (Thrusfield 2005). However, due to the limitation of time, the present study uses deterministic modelling.

This study used the Codex Alimentarius Commission risk assessment system (Codex Alimentarius Comission 1999) which comprises 7 steps (Box 7.2), since the risk for marketed milk is assessed (see Section 7.1.4 Risk analysis). The purpose of the risk assessment was 'to assess the risk of purchasing raw milk infected with *Brucella abortus* for populations living in urban areas of Kampala during rainy season per day'. Hazard identification of brucellosis was done in the introduction to this chapter.

Box 7.2 Process of the Codex Alimentarius Commission risk assessment
(Codex Alimentarius Commission 1999)

1. Statement of purpose of risk assessment

2. Hazard identification

The identification of biological, chemical, and physical agents capable of causing adverse effects and which may be present in a particular food or group of foods.

3. Exposure assessment

The qualitative and/or quantitative evaluation of the likely intake of biological, chemical, and physical agents via food as well as exposures from other sources if relevant.

4. Hazard characterization

The identification and/or quantitative evaluation of the nature of the adverse health effects associated with the hazard.

5. Risk characterization

The process of determining the qualitative and/or quantitative estimation, including attendant uncertainties, of the probability of occurrence and severity of known or potential adverse health effects in a given population based on hazard identification, hazard characterization and exposure assessment.

6. Documentation

7. Reassessment

7.2.3. Designing a milk distribution model

For an exposure assessment of the risk of purchasing marketed raw milk infected with *B. abortus* in urban areas of Kampala per day, it was necessary to quantify market chains for milk and infection rates with *B. abortus* in these areas. A basic milk distribution model was designed with three pathways: through 1) milk shops and milk vendors, 2) milk traders carrying a milk can on a bicycle, and 3) local consumption (Fig 7.2) so that risk distribution was quantified by multiplying with

infection rate of each pathway. The quantity of milk and its infection rate with *B. abortus* on pathways 2) and 3) had been determined in the cattle survey described in Chapter 6. However, the quantity of milk and its infection rate with *B. abortus* through milk shops and milk vendors had not been determined. The source of milk bicycle traders carrying a can sold had not been examined in detail. A milk shop survey was carried out to describe the entire market chain for milk and to estimate infection rate of milk with *B. abortus* in each pathway.
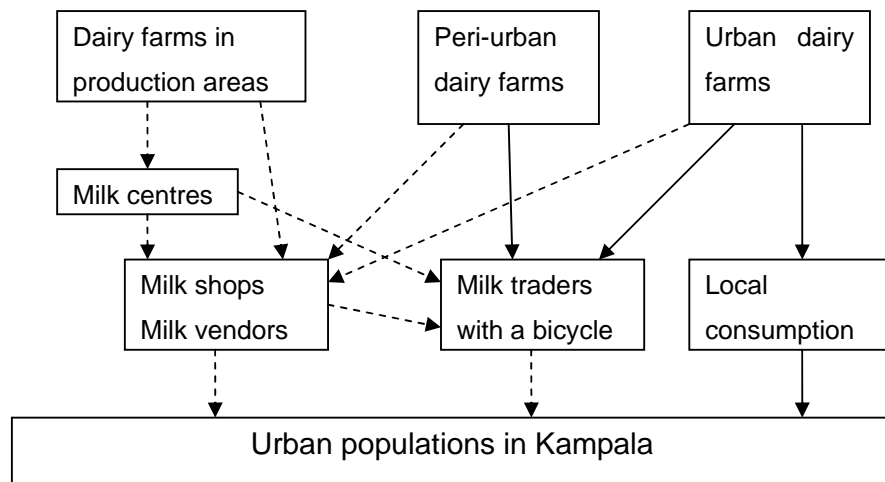
Fig. 7.2 A design of a basic milk distribution model in urban areas of Kampala. Two pathways on the right were studied partly in brucellosis cattle survey described in Chapter 6. Dotted lines represent unknown pathways to be investigated in the present study.

7.2.4. Milk shop survey

7.2.4.1. Sampling framework

This study used multi-stage cluster sampling (Thrusfield 2005) with a stratified random sampling in the selection of LC1s: clusters (Box 7.3). Sampling units were all types of milk seller. Selection of the clusters (LC1s) is described in the next section.

Box 7.3 Sampling framework in the milk sampling

1. External population

Milk sellers in urban areas of Kampala (other than Central Kampala, Makindye and Rubaga Division)

2. Clusters

48 urban LC1s selected using stratified random sampling

3. Sampling units

All milk sellers in the 48 urban LC1s selected using stratified random sampling

---

7.2.4.2. Definition of types of milk seller

Most milk sold in Kampala is not packaged but measured out for the customer at point of sale (usually a half litre or a litre). This informal milk is sold at half of the price of packaged milk. Such informal milk sales are carried out by several types of milk seller (Box 7.4).

Box 7.4 Definitions of types of informal milk sellers seen in Kampala

1. Milk shop with a bulk cooler (Fig 7.4)

Milk shops storing milk in a bulk cooler which shape is either box or cylinder. There are two types: wholesaler and retailer.

2. Milk shop with a small refrigerator (Fig 7.5)

Milk shops storing milk in a small refrigerator.

3. Milk shop without a refrigerator

Milk shops storing milk in a basin at an ambient temperature.

4. Milk trader with a milk can on a bicycle (Fig 7.6, Fig 7.7)

There are three types: 1) those who buy milk at peri-urban farms and sell to contracted individual households and passing trade, 2) those who buy at milk boiling centres and sell to contracted individual households and passing trade, 3) those who buy milk at wholesaler bulk cooler milk shops and sell to contracted individual households and passing trade or smaller milk shops.

5. Roadside milk vendor (Fig 7.8, Fig 7.9)

Milk vendors selling milk at roadside in the early mornings and the evenings. There are three types: 1) those who buy milk at peri-urban farms and sell milk on the roadside in trading centres, 2) those who buy milk at boiling centres and sell milk on the roadside in trading centres, 3) those who cook milk tea on the roadside (however this type is excluded from the present study since this milk is boiled and therefore not a risk).

Fig. 7.3 A milk shop with a bulk cooler

Fig. 7.4 A milk shop with a small refrigerator

Fig. 7.5 Milk vendors with a milk can on a bicycle

Fig. 7.6 A milk vendor with a milk can on a bicycle at a peri-urban dairy farm

Fig. 7.7 A roadside milk vendor selling milk bought at a boiling centre

Fig. 7.8 A roadside milk vendor selling milk bought at a peri-urban dairy farm

7.2.4.3. Interviews with milk sellers

All the milk shops and roadside milk vendors in the 48 LC1s and milk sellers with milk cans on a bicycle encountered on the road were interviewed during September and October in 2007 using a questionnaire (see Box 7.5; details are shown in Appendix IV). When the source of milk was larger milk shops or boiling centres within Kampala, these sources were visited and interviewed using the same questionnaire; interviews revealed the detailed market chain for milk in Kampala. Milk traders carrying milk cans on a bicycle who were encountered in urban areas, and the large scale wholesale milk shops and boiling centres which were the source of milk for milk sellers in the 48 LC1s were also interviewed. Interviews were conducted for English speakers in English, and for non-English speakers in Luganda by the author. The driver of the research vehicle assisted with the interviews as he spoke both English and Luganda.

Box 7.5 Contents of the interview about milk sales

Source of milk
Quantity of milk sales per day (L/day)
Working day per week (days/week)
Boiling practice of milk
Methods of milk transportation
Price of milk (Ugandan Shilling/L)
Where customers are from

7.2.4.4. Milk sampling

Milk was sampled at all interviewed milk sellers, milk traders with milk cans on a bicycle, and the large scale wholesale milk shops and boiling centres in Kampala, which were the source of milk for milk sellers. Five packages of pasteurised milk were also purchased for sampling. Milk was sold out at some milk sellers when they were visited and in such cases, interviews were carried out without collecting milk samples.

Milk was sampled using a disposable Pasteur pipette and transferred into an Eppendorf tube. The milk sample were put in a cool box immediately after sampling and carried to the Central Laboratory in the Department of Veterinary Medicine, Faculty of Veterinary Medicine, Makerere University, Uganda where samples were stored in a freezer at - 20˚C.

7.2.4.5. Milk IELISA test

Indirect enzyme-linked immunosorbent assay (IELISA) was used because the milk ring test was expected to give false-positive reactions with bulk milk produced by vaccinated cattle herds. Sampled milk was tested at the Department of Molecular Microbiology, Faculty of Veterinary Medicine, Makerere University using IELISA kit purchased from the Veterinary Laboratory Agency, UK. Optical density (OD) values were read using a calibrated ELISA plate reader, and samples were diagnosed for brucellosis accordingly.

7.2.5. Statistical analysis

7.2.5.1. Milk IELISA test results

The rates of positive milk samples from IELISA tests were compared for each type of milk seller. Chi-square test was used to calculate 95% confidence intervals using statistical software R2.4.1.

7.2.5.2. Boiling of marketed milk

Since *B. abortus* bacilli are killed by boiling milk, the proportion of milk sellers who boil milk before sales for each type of milk seller is an essential risk input to determine the total risk. The proportion of milk sellers who boiled milk before sales in each type of milk sellers and their confidence intervals were calculated using Chi-square test with the statistical software R 2.4.1.

7.2.5.3. Comparison of infection rates of raw milk from different sources

Infection rate of milk with *B. abortus* is another essential risk input to determine the risk for each risk pathway. Milk sold in Kampala is transported from several dairy production areas. Ideally, infection rate of milk with *B. abortus* is best determined for each dairy production area; however in the present study, the number of samples from some production areas was not great enough to determine infection rates accurately. Infection rates of milk from different dairy production areas were examined for a significant difference among them using a Generalised Linear Model with binomial errors using the statistical software R 2.4.1, in order to decide whether overall infection rate can be used as a risk input, instead of using individual infection rates.

Chapter 6 determined the infection rate of milk produced in urban and peri-urban areas of Kampala using CELISA which is more sensitive and specific test than IELISA. To use this infection rate as a risk input, the infection rates of milk sourced from dairy production areas other than peri-urban Kampala were tested for significant differences using GLM with binomial errors with the statistical software R 2.4.1. The overall infection rate of milk from dairy production areas other than peri-urban Kampala was calculated in this way.

For the presentation of infection rates of milk from different dairy production areas, 95% confidence intervals were calculated using Chi-square test in R 2.4.1.

7.2.5.4. Overall true infection rate

Milk IELISA, which was used in this study, is a sensitive and specific test but is regarded as an imperfect test for pooled and diluted milk samples (Nielsen 1996). The overall true infection rate of milk with *B. abortus* was calculated using the Formula 7.1 (Rogan 1978; Thrusfield 2005) with sensitivity and specificity of milk IELISA, 0.953 and 0.951. Sensitivity and specificity was taken from a study that used bulk milk and individual cattle (Rivera 2003) as the milk samples of the present study were pooled. The confidence interval was calculated using Formula 7.2 (Thrusfield 2005).

Formula 7.1 A corrected true prevalence estimated using an imperfect test

$$P = \frac{P^T + \text{specificity} - 1}{\text{sensitivity} + \text{specificity} - 1}$$

where P^T is the test prevalence.

Formula 7.2 An approximate 95% confidence interval for cluster samples

$$P - 1.96 \left\{ \frac{c}{T} \sqrt{\frac{V}{c(c-1)}} \right\}, \quad P + 1.96 \left\{ \frac{c}{T} \sqrt{\frac{V}{c(c-1)}} \right\}$$

Where:

c = number of clusters (LC1s) in the sample;

T = total number of milk shops in the sample;

and:

$$V = P^2 \left(\sum n^2 \right) - 2P \left(\sum nm \right) + \left(\sum m^2 \right)$$

Where:

n = number of milk shops sampled in each LC1

m = number of positive milk samples in each LC1

7.2.6. Spatial epidemiology of milk market chains

Spatial patterns in the market chains for milk were plotted in maps to define the steps in milk distribution and the spatial risk of purchasing raw milk infected with *B. abortus*.

The locations of milk sellers, milk traders with a milk can on a bicycle, large-scale wholesale milk shops and boiling centres were recorded with handheld GPS (Garmin, Olathe, KS, USA). The National Biomass Study, from which the spatial data layers were obtained, is provided in the Universal Transverse Mercator (UTM) projection, with the detailed parameters as shown in Box 2.2 (Chapter 2). GPS data were collected in latitude/longitude format, in the WGS 84 datum, and were converted for the Biomass projection for processing of maps using ArcView 3.1 Geographic Information System (ESRI Systems, Redlands, CA, USA). The maps of quantity of milk sales in each stage of the market chain were made using ArcGIS9 Geographic Information System (ESRI systems, Redlands, CA, USA).

7.2.7. Development of the quantitative milk distribution model

Interviews with milk sellers in the 48 LC1s revealed detailed market chains in urban Kampala - the quantities of milk sales obtained from interviews in the 48 LC1s - were multiplied by the reciprocal of the sample fraction of LC1s (9.08, 790/87 LC1s, see Section 7.2.4.2) to obtain the quantities of milk sold per day in the urban areas of Kampala. The quantities of milk sold per day in the milk boiling centres and large-scale wholesale milk shops were not multiplied in this way as all of them were studied.

The milk distribution model was assembled using these quantified market chains and quantified dairy production in urban and peri-urban areas of Kampala in which milk is distributed via farm gate purchasing and milk traders with a bicycle (details are described in Chapter 6).

7.2.8. Exposure assessment

In this study, the situation which all the unpackaged milk consumed in urban areas of the Kampala economic zone is infected with *B. abortus* when purchased (including home consumption by dairy farmers) is defined as risk 1, and the risk was presented as a proportion.

To calculate the risk for each type of milk seller, firstly infection rate at sale was obtained by multiplying the infection rate of raw milk by the proportion of milk that was not boiled, and secondly the infection rate at sale was multiplied by the proportion of milk sold by the type of milk seller out of total milk consumption in urban Kampala. Finally, the total risk was calculated by adding up the risks for all types of milk seller.

The overall true infection rate of milk from dairy production areas other than peri-urban Kampala was used as the infection rate of raw milk for the categories: milk shop with a bulk cooler and with a small refrigerator. For milk vendors with a milk can on a bicycle, the infection rate was calculated by adding the product of the proportion of milk sourced from peri-urban Kampala and the infection rate obtained

from Chapter 6 (18.6%, Section 6.3.11), and the product of the proportion of milk sourced from the other dairy production areas and the overall true infection rate. For roadside milk vendors, milk shops without a refrigerator, and farm gate, the infection rate obtained from Chapter 6 (18.6%) was used as the infection rate of raw milk.

7.2.9. Hazard characterisation

The hazard was characterised qualitatively for the severity and duration of adverse effects that may result from purchasing raw milk infected with *B. abortus* (Codex Alimentarius Commission 1999). The method used a six point scale for measuring hazard: negligible, very low, low, moderate, harmful and very harmful.

7.2.10. Risk characterisation

The risk of purchasing raw milk infected with *B. abortus* in urban areas of Kampala was characterised semi-quantitatively by integrating hazard identification, exposure assessment and hazard characterisation (Codex Alimentarius Commission 1999). The risk was described quantitatively, and considering the hazard characteristic, the risk was characterised qualitatively using a six point scale measurements: negligible, very low, low, moderate, high and very high.

7.2.11. Options for human brucellosis control in urban areas of Kampala

As a risk management, possible control options to reduce the risk of purchasing raw milk infected with *B. abortus* in urban areas of Kampala were listed based on the

developed risk model. The possible reductions in risk were calculated quantitatively using the risk for each type of milk seller calculated in the previous section, with some modification using the quantified milk distribution model. Necessary public investment and feasibility were estimated qualitatively.

7.2.12. The degree of confidence for risk estimates

The degree of confidence in the final estimation of risk and risk management was determined qualitatively considering the uncertainly and assumptions identified in all the steps (Codex Alimentarius Commission 1999). Uncertainty is associated with the data themselves and with the choice of model. Variability (stochastic uncertainty (Vose 2000)) could not be fully assessed since stochastic modelling was not used in the present study. The variability, uncertainty and degree of confidence were expressed using five scale measurements: very low, low, moderate, high and very high.

7.3. Results

7.3.1. Milk IELISA test

Table 7.2 shows the results of IELISA for milk samples. Surprisingly, positive milk samples were collected only from milk shops with bulk cooler and milk shops with small refrigerator. The percentages of positive milk in milk boiling centre and packed pasteurised milk have a wide range of confidence intervals due to the small number of samples; however, as the milk was pasteurised before sale, the confidence intervals should be very narrow and close to zero in reality. On the contrary, although there were no positive samples from milk shops without refrigerator, roadside milk vendor, milk vendors carrying a milk can on a bicycle were small, if all these milk sellers sell raw milk, true positive rates could be high as the confidence intervals showed. The next section examines boiling practice of the milk sellers to determine this essential risk input.

Table. 7.2 Milk IELISA results

Type	Positives	Sample	Percentage (95% CI)
Milk shop with bulk cooler	7	44	15.9 (7.2 – 30.7)
Milk shop with small refrigerator	6	40	15.0 (6.2 – 30.5)
Milk shop without refrigerator	0	3	0.0 (0.0 – 69.0)
Roadside milk vendor	0	5	0.0 (0.0 – 53.7)
Milk vendor with bicycle	0	22	0.0 (0.0 – 18.5)
Milk boiling centre	0	4	0.0 (0.0 – 60.4)
Packaged pasteurised milk	0	5	0.0 (0.0 – 53.7)
Total	13	123	10.6 (6.0 – 17.7)

7.3.2. Boiling activities of marketed milk

Table 7.3 shows the boiling activities of milk sellers. Total number of interviews (n=143) is greater than number of milk samples (n=123) since some of interviewed milk shops ran out of milk at the time of interview.

In total, 17.5% (25/143, 95%CI: 11.8 – 24.9) of milk sellers boiled milk. None of the milk shops with a bulk cooler boiled milk. Out of the 52 milk shops with a small refrigerator, 8 shops (15.4%, 95%CI: 7.3 – 28.6) boiled milk: 2 shops bought milk from boiling centres, 1 shop bought boiled milk at the farm, and 5 shops boiled a proportions of milk at the shop. A half (3/6, 50%, 95%CI: 18.8 – 81.2) of milk shops without a refrigerator sold boiled milk: one shop boiled all milk, one shop 5 of 20 litres at the shops, and the other one shop bought from a boiling centre. Three out of five (60%, 95%CI: 17.0 – 92.7) roadside milk vendors sold milk that was boiled; these three bought from boiling centres, and the other two bought raw milk from farms in peri-urban areas. One out of 22 milk traders/vendors with a milk can on a bicycle sold boiled milk: one bought milk from a boiling centre, three bought from milk shops with bulk cooler, and the rest, 18 bought from farms in peri-urban areas of Kampala. All boiling centres boiled milk, and all packaged milk was pasteurised.

Table. 7.3 Boiling activities of milk sellers

Type	Boiling	Interviewed	Percentage (95% CI)
Milk shop with bulk cooler	0	48	0.0 (0.0 - 9.2)
Milk shop with a small refrigerator	8	52	15.4 (7.3 – 28.6)
Milk shop without a refrigerator	3	6	50.0 (18.8 – 81.2)
Roadside milk vendor	3	5	60.0 (17.0 – 92.7)
Milk vendor with bicycle	1	22	4.5 (0.2 – 24.9)
Milk boiling centre	5	5	100.0 (46.3 – 100.0)
Packed pasteurised milk	5	5	100.0 (46.3 – 100.0)
Total	25	143	17.5 (11.8 – 24.9)

7.3.3. Infection rates of raw milk

Necessary risk inputs for a risk model in the present study are: quantity of milk, infection rate, and the proportion of boiling practice in each risk pathway. In Table 7.2, the milk IELISA positive rates included boiled milk. To calculate the infection rates with *B. abortus*, the milk IELISA test results for raw milk samples were used (Table 7.4). For milk shops with a bulk cooler, all of which did not boil milk, the infection rate was the same as in Table 7.2. For milk shops with a small refrigerator, as six out of 40 milk samples had been boiled, the infection rate of raw milk was 17.6% (6/34, 95%CI: 7.4 – 35.2). For milk shops without a refrigerator, milk was sampled from three out of six milk shops interviewed, and two of the three milk shops sampled boiled milk at the shops; only one raw milk sample was collected from a milk shop without a refrigerator, and the infection rate for raw milk was 0% (0/1, 95%CI: 0-94.5). For milk traders/vendors with a milk can on a bicycle, as one sample was boiled, the infection rate and confidence interval of raw milk were 0% (0/21, 95%CI: 0.0 – 21.9).

Table. 7.4 Infection rates of raw milk with *B. abortus*

Type	Positives	Sample	Percentage (95% CI)
Milk shop with bulk cooler	7	44	15.9 (7.2 – 30.7)
Milk shop with small refrigerator	6	34	17.6 (7.4 – 35.2)
Milk shop without refrigerator	0	1	0.0 (0.0 – 94.5)
Roadside milk vendor	0	2	0.0 (0.0 – 80.2)
Milk vendor with bicycle	0	21	0.0 (0.0 – 21.9)
Total	13	102	12.7 (7.2 – 21.2)

7.3.4. Comparison of infection rate of raw milk according to the source

Infection rates for milk from each type of milk seller shown in the previous section (Table 7.4) did not take differences in infection rates from different sources of milk into account. Table 7.5 shows infection rates of raw milk with *B. abortus* according to the source of milk. For some large-scale milk shops with a bulk cooler in Bwaise and Kawempe (Fig 7.10, Section 7.3.6.2), the source of milk were both Mbarara and Nakasongola dairy production areas (Fig 7.9, Section 7.3.6.1) and this group was categorised as "Mbarara & Nakasongola mixed" (Table 7.5). Among these five categories of source of milk in Table 7.5, there was no significant difference in infection rates using GLM (p=0.200). Overall, 12.7% (95% CI: 7.2 – 21.2) of milk samples were positive using IELISA. As the precision of infection rate increases with sample size, this overall infection rate was thought to be better to use as a risk input, rather than using individual infection rates with lower precision.

The prevalence of brucellosis at herd level in urban and peri-urban areas of Kampala was studied using CELISA which has higher sensitivity and specificity than IELISA (Chapter 6), and the infection rate of milk obtained by this method is a more robust risk input than the infection rate of milk sourced from peri-urban Kampala in the present study.

Differences in infection rates were examined among the sources of milk other than peri-urban Kampala, to test whether these infection rates can be combined. Using a GLM, there was no significant difference among these infection rates (p=0.633). The overall infection rate of milk sourced from dairy production areas other than

peri-urban Kampala was 16.7% (95% CI: 9.3 – 27.7).

Table. 7.5 Infection rate of raw milk according to the source

Source	Positives	Sample	Percentage (95% CI)
Mbarara and neighbours	8	57	14.0 (6.7 – 26.3)
Nakasongola, Kiboga	1	3	33.3 (1.8 – 87.5)
Rural Mukono, Kayunga	2	6	33.3 (6.0 – 75.9)
Peri-urban Kampala	1	30	3.3 (0.2 – 19.1)
Mbarara & Nakasongola mixed	1	6	16.7 (0.9 – 63.5)
Total	13	102	12.7 (7.2 – 21.2)
Other than peri-urban Kampala	12	72	16.7 (9.3 – 27.7)

7.3.5. True infection rate

As IELISA was regarded as an imperfect test for this study, true infection rate was calculated using overall infection rate sourced from dairy production areas other than peri-urban areas of Kampala (16.7%). The true infection rate was 13.1% (95%CI: 7.1 – 19.1).

7.3.6. Spatial epidemiology of quantified market chains for milk

Spatial patterns in the quantified market chains for milk are shown in maps to describe the steps in milk distribution and the spatial risk of purchasing raw milk infected with *B. abortus*.

7.3.6.1. Dairy production areas outside Kampala

Fig 7.9 shows quantities of raw milk transported from dairy production areas to urban areas of Kampala; the width of the arrows represents quantity of milk. The majority of raw milk was transported from Mbarara and neighbouring districts (Kiruhura, Sembabule and Rakai). There were two other dairy production areas transporting milk to urban Kampala: north of Kampala (Kiboga and Nakasongola), and east (Kayunga and rural Mukono).
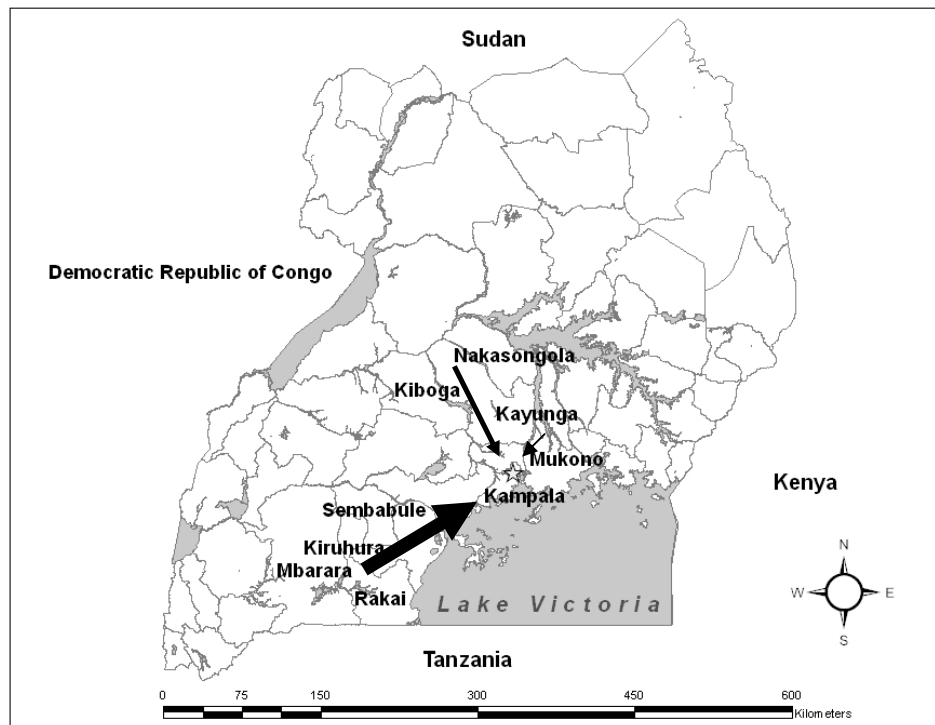
Fig. 7.9 Map of Uganda showing transportation of raw milk from dairy production areas

7.3.6.2. Wholesale milk centres and milk boiling centres

There were three routes of raw milk transportation from dairy production areas outside Kampala: milk boiling centres, milk shops with a bulk cooler and milk shops with a small refrigerator. Some milk sold in small-scale milk shops with a bulk cooler was sourced from wholesale milk centres comprising several large-scale milk shops with a bulk cooler, and some of the milk sold in milk shops with a small refrigerator was sourced from these wholesale milk centres or milk boiling centres (detailed market chains for milk are described in Section 7.3.7).

Fig 7.10 shows the spatial distribution of wholesale milk centres and milk boiling centres in Kampala. Filled and hollow circles represent IELISA positive shops and negative shops respectively, and squares represent milk boiling centres. The size of symbols represents quantity of the milk sales. There were 8 milk shops in Bwaise centre, 8 shops in Nateete centre, 5 shops in Kawempe centre and 5 shops in Kitintale centre. Katwe centre had only 2 milk shops but the sales quantity was the largest (10,700 L/day). There were two large milk boiling centres in Bwaise and Ndeeba (Fig 7.10). Ndeeba had two boiling centres that boil 3,300 L/day in total. Nateete also had two milk boiling centres that boil 50 L/day in total. The source of milk in Bwaise boiling centre was Nakasongola and that of Ndeeba and Nateete boiling centres was Mbarara.
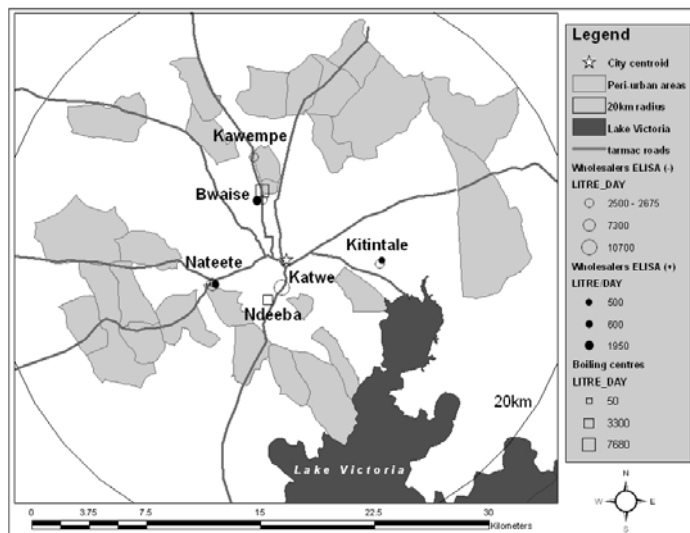
Fig. 7.10 Spatial distributions of wholesale milk shop centres and milk boiling centres

7.3.6.3. Milk shops with a bulk cooler

Fig 7.11 shows the spatial distribution of milk shops with a bulk cooler in Kampala. Most of the shops were located along the main road, but they were scattered in all directions. Blank areas without shops observed west and southeast of city centroid were Rubaga, Makindye and Central Kampala Division which were not studied.
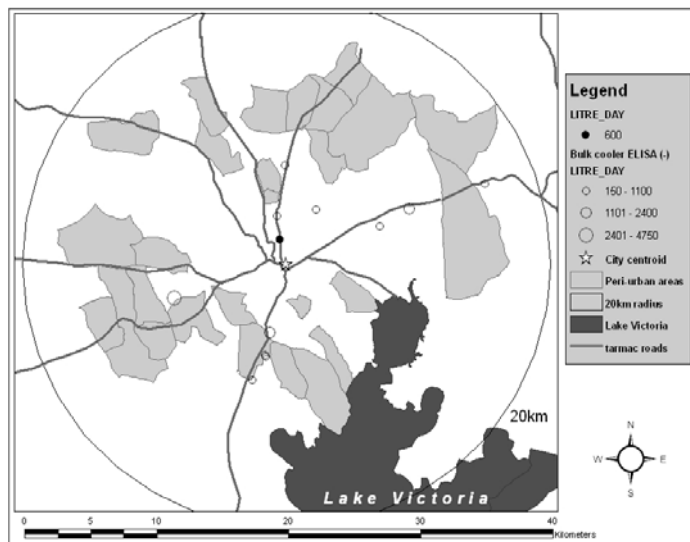
Fig. 7.11 Spatial distributions of milk shops with a bulk cooler

7.3.6.4. Milk shops with a small refrigerator

Milk shops with a small refrigerator were scattered further than shops with a bulk cooler. However, they were still located along the trunk roads. Therefore, urban dwellers living far from trunk roads might buy milk from milk vendors with a milk can on a bicycle or farm gate unless they travel to the trunk roads.
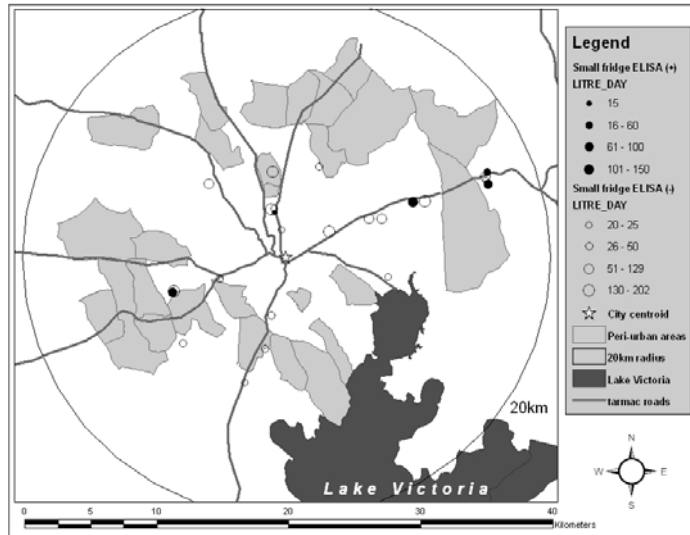
Fig. 7.12 Spatial distributions of fresh milk shops with a small refrigerator

Significant spatial risk factors for purchasing of raw milk infected with *B. abortus* in urban areas of Kampala were not found since (1) milk shops with a bulk cooler and with a small refrigerator selling milk that was not boiled were scattered along trunk roads, (2) milk vendors with a milk can on a bicycle mostly sold milk that was not boiled and (3) urban dairy farmers might sell milk in areas far from trunk roads.

7.3.7. The quantitative milk distribution model

Interviews with milk sellers in the 48 LC1s that traced the milk source revealed the detailed market chains of urban Kampala. Fig 7.13 shows the quantitative milk distribution model which was assembled using these market chains and the quantified dairy production in urban and peri-urban areas of Kampala in which milk is distributed via farm gate purchasing and milk traders with a bicycle (details are described in Chapter 6).

In Fig 7.13 solid lines represent flow of raw milk and dotted lines boiled milk. The width of the lines shows the quantity of milk. Each day, 212,454 litres of unpackaged milk (including both raw and boiled) was consumed in urban areas of Kampala, and 199,774 litres (94.0%) were not boiled before selling. Of this raw milk, 160,610 litres (80.4%) was transported from dairy production areas outside Kampala. The largest source of raw milk which consumers purchased was milk shops with a bulk cooler which sold 125,426 litre of milk per day; this represents 62.8% of the total amount of raw milk consumed in urban areas and 59.0% of all urban unpackaged milk (shown as 'bulk cooler milk shops' and 'bulk cooler' in Fig 7.13). The majority of milk sold in milk shops with a bulk cooler was transported from Mbarara and its neighbouring districts (121,064 L/day) that contributed 96.5% of milk sold in this type of milk shops. The other sources of milk sold in milk shops with a bulk cooler were peri-urban areas of Kampala (1,362 L/day, 1.1%) and farms in Nakasongola and Kiboga Districts (3,000 L/day, 2.4%): 800 litres were sold to wholesale shops and 2,200 litres to shops in Bwaise.
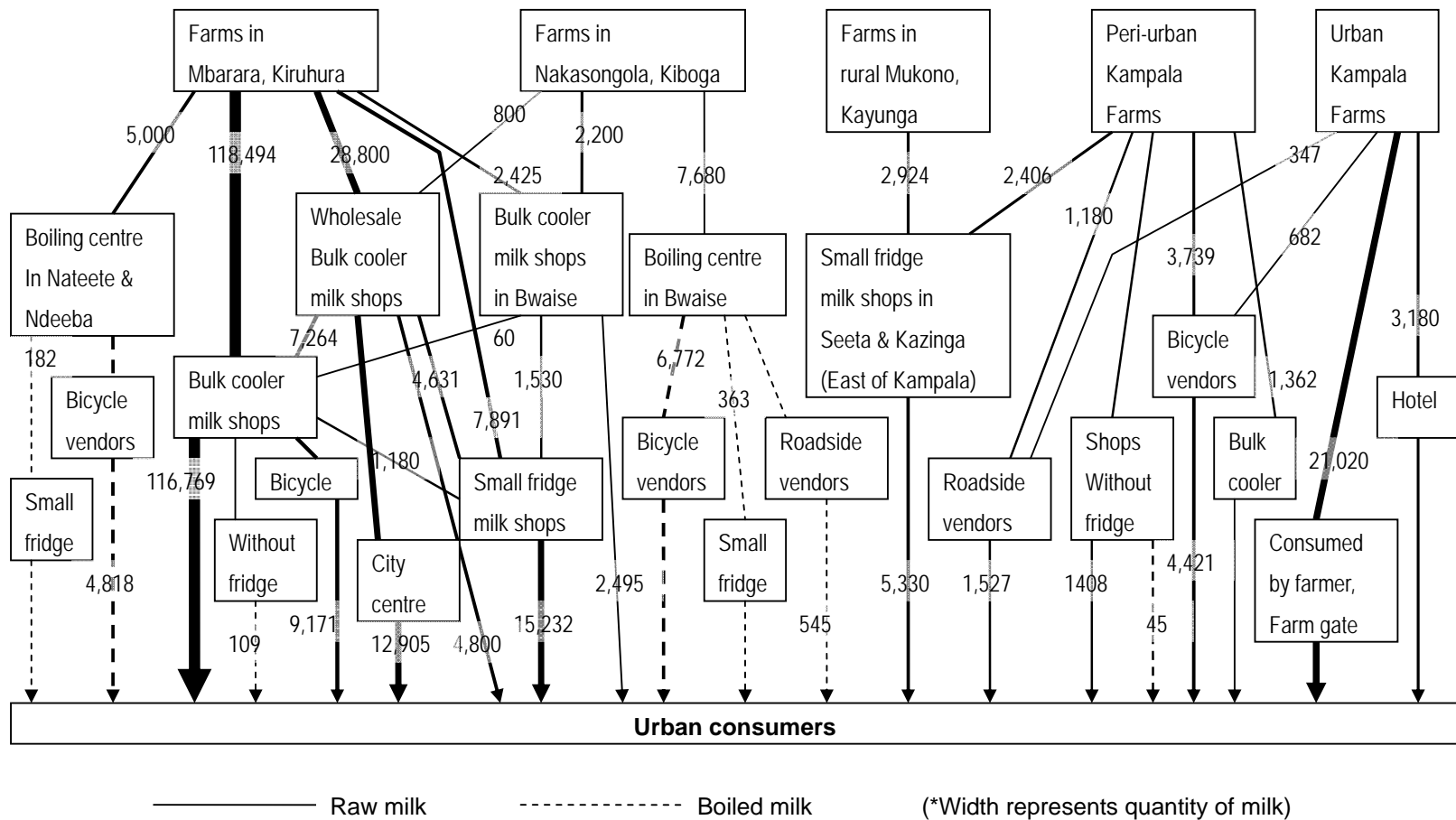
Fig. 7.13 Quantified unpackaged milk distribution model in urban areas of the Kampala economic zone (L/day)

The majority of milk produced in urban dairy farms was consumed by families of the farmers themselves and their neighbours (21,020 L/day, 83.3% of total urban milk production); this was the second largest source of milk consumed in urban Kampala (9.9% of total urban unpackaged milk consumption). The milk was sold to neighbours without boiling but all urban dairy farmers boiled milk before consumption at home, according to the interviews with dairy farmers (Chapter 6). The third largest source of raw milk consumed in urban Kampala was milk shops with a small refrigerator (21,107 L/day, 9.9% of total urban unpacked milk consumption) of which 97.9% (20,662 L/day, 10.3% of total urban raw milk sales) was not boiled (shown as 'small fridge' in Fig 7.14).

The difference between the total amount of milk sales in wholesalers and the total amount of milk sales in retail shops minus described amount of direct purchase by consumers at wholesalers was most likely to have been sold to retail shops in Rubaga, Makindye and Central Division of Kampala District which were excluded from the present study (shown as 'city centre' in Fig 7.14).

The amount of milk sold by milk traders/vendors with a milk can on a bicycle (25,182 L/day; which is shown as 'bicycle' in Fig 7.13), accounted for 11.9% of total urban unpackaged milk sales, and 13,592 litres (54.0%) was not boiled. Roadside milk vendors sold only 1.0% (2,072 L/day) of total urban unpackaged milk; 70.1% of this milk (1,453) was not boiled. The milk shops without refrigerator sold even less milk (1,562, 0.7% of total urban unpacked milk sales); and 9.9% of this milk was boiled (shown as 'without fridge' in Fig 7.13).

7.3.8. Exposure assessment

As an exposure assessment, the situation which all the unpackaged milk consumed in urban Kampala is infected with *B. abortus* when purchased is defined as risk 1, and the risk was presented as a proportion.

7.3.8.1. Infection rate at sale

First of all, the infection rate at sale was calculated by multiplying infection rate of raw milk by the proportion of milk which was not boiled for each type of milk seller (Table 7.6).

Table. 7.6 Infection rates of unpackaged milk with *B. abortus* at sale

Type	Infection rate at sale (%)	Not boiled (%)	Infection rate of raw milk (%)
Milk shop with a bulk cooler	13.1	100	13.1
Milk shop with a small refrigerator	11.2	97.9	13.1
Milk vendor with a milk can on a bicycle	8.0	54.0	14.1
Roadside milk vendor	13.0	70.1	18.6
Milk shop without refrigerator	16.8	90.1	18.6
Farm gate	18.6	100	18.6
Business hotels	0.0	0.0	18.6

For the infection rate of raw milk for the categories, milk shop with a bulk cooler and with a small refrigerator, the overall true infection rate of milk from dairy production

areas other than peri-urban Kampala (13.1%) was used. For milk vendors with a milk can on a bicycle, the infection rate (14.1%) was calculated by adding the product of the proportion of milk sourced from peri-urban Kampala and the infection rate obtained from Chapter 6 (18.6%), and the product of the proportion of milk sourced from the other dairy production areas and the overall true infection rate (13.1%). For roadside milk vendors, milk shops without a refrigerator, farm gate, and business hotels, the infection rate obtained from Chapter 6 (18.6%) was used. Boiling activity was not interviewed at business hotels but all hotels were supposed to boil milk.

7.3.8.2. The risk distributed by milk sellers

To calculate the risk for each type of milk seller, the infection rate at sale was multiplied by the proportion of milk sold by the type of milk seller out of total milk consumption in urban Kampala. The proportion of milk sold by type was calculated by dividing the quantity of the milk sold by the type of milk seller by the total quantity of unpackaged milk sold per day using the quantitative milk distribution model. Finally, the total risk was calculated by adding up the risks for all types of milk seller.

According to the results in Table 7.7, the risk of purchasing raw milk infected with *B. abortus* was largest in milk shops with a bulk cooler (0.077, 66.4% of the total risk); milk shops with a bulk cooler were found to be the most responsible for human brucellosis in urban areas of Kampala. Farm gate purchasing of milk was the second largest risk (0.018, 15.8%), and milk shops with a small refrigerator the third (0.011, 9.5%). Milk vendors with a milk can on a bicycle were also responsible for some

infections (0.010, 8.2%) but roadside milk vendors (<0.001) and milk shops without a refrigerator (<0.001) contributed much smaller risks for human brucellosis in urban Kampala. The total risk was 0.117 and it meant 11.7% of unpackaged milk sold in urban Kampala, including milk in hotels and canteens, contained *B. abortus*.

Table. 7.7 Risk of brucellosis distributed by different types of milk seller

Type	Risk of brucellosis distributed	Proportion of milk sold (%)	Infection rate at sale (%)
Milk shop with bulk cooler	0.077	59.0	13.1
Milk shop with small fridge	0.011	9.9	11.2
Milk vendor with bicycle	0.010	11.9	8.0
Roadside milk vendor	<0.001	1.0	13.0
Milk shop without fridge	<0.001	0.7	16.8
Farm gate	0.018	9.9	18.6
Business hotels	<0.001	7.6	0
Total	0.117	100	

7.3.9. Hazard characterisation

Hazard is defined as the severity and duration of adverse effects that may result from a risk. Purchasing of raw milk infected with *B. abortus* does not necessarily cause infections in humans as the agent can be killed by boiling milk. However, once the infection is established, the agent causes continued, intermittent or irregular fever, headache, weakness, profuse sweating, chills, arthralgia, depression, weight loss, generalised aching, localised suppurative infections of organs, orchitis and epididymitis (Chin 2000). Due to the chronic nature of human brucellosis, this disease can severely affect household incomes. In Uganda, human brucellosis is often clinically confused with malaria, which may cause delays in starting treatment (personal communication by physicians in Mulago National Referral Hospital). Brucellosis is curable; conventional therapy for brucellosis in Uganda is oral doxycycline for 6 weeks and intramuscular injection of streptomycin for 2 weeks (Kyebambe 2005). Dose-response (Codex Alimentarius Commission 1999) for the treatment is moderate as duration of the treatment is long but the drugs are not expensive; however patients may be easily re-infected unless urban populations are well informed about the risk of purchasing raw milk.

Considering the chronic nature of brucellosis, confusion in diagnosis and its curability, the hazard was characterised as 'harmful' by the six point scale measurement for hazard (negligible, very low, low, moderate, harmful and very harmful).

7.3.10. Risk characterisation

The risk of purchasing raw milk infected with *B. abortus* in urban areas of Kampala was characterised semi-quantitatively by the integration of hazard identification, exposure assessment and hazard characterisation (Codex Alimentarius Commission 1999).

In total, 11.7% of unpackaged milk sold in urban areas of Kampala contained *B. abortus*. Considering the harmful characteristic of the risk, the risk of purchasing raw milk infected with *B. abortus* (94.0% of unpackaged milk is not boiled - Section 7.3.7) is 'high' by the six point scale measurement for the risk (negligible, very low, low, moderate, high and very high).

7.3.11. Control options of human brucellosis in urban areas in Kampala

Table 7.8 shows control options which could reduce the risk of purchasing raw milk infected with *B. abortus* and the percentages of risk reduction. The most effective control option was to construct boiling centres in peri-urban areas and enforce milk traders from dairy production areas and peri-urban areas to sell their milk to these centres. The costs of this option would be high as several boiling centres will be required to be constructed at different direction from Kampala city. Also, this option requires legislation and was thought difficult to enforce. The second most effective control option was to construct milk boiling centres in Mbarara dairy production areas and to enforce dairy farmers in the areas to sell milk to these boiling centres. Public investment was judged to be less than option one as the number of boiling centres could be smaller, and land price should be cheaper than the first option. However it will raise retail price of milk and persuading dairy farmers should be a challenge. The third most effective control option was to enforce milk shops to boil milk. This option costs very little, requiring only means of regularly checking of boiling practice. However, this was not a feasible option for shop owners in terms of space, facility, labour force and cost. Ban of milk sales by vendors with milk cans on a bicycle in urban areas, farm gate milk sales and urban dairy farming would not reduce the risks dramatically. They are feasible options but the livelihoods of these dairy farmers and traders would be affected. Bans on roadside milk sales and milk sales at milk shops without refrigerator were the least effective options.

Table. 7.8 Control options to reduce the risk of purchasing raw milk infected with *Brucella abortus* in urban Kampala

Options	Reduction of risk (%)	Public investment	Feasibility
Construct boiling centres in Mbarara dairy production areas	77.3	Middle	Middle
Construct boiling centres in peri-urban areas and enforce milk traders from dairy production areas and peri-urban areas to sell milk to them	84.2	High	Low
Enforce to boil milk at milk shops	75.9	None	Very low
Ban of milk sales by vendors with a milk can on a bicycle in urban areas	8.2	Work load of police	Middle
Ban of roadside milk sales	0.1	Work load of police	Middle
Ban of milk sales without refrigerator	0.1	Work load of officers	Middle
Ban of farm gate milk sales	15.8	Work load of officers	Low
Ban of urban cattle farming	15.8	Work load of officers	Middle

7.3.11.1.The degree of confidence in final estimation of the risk

Variability (stochastic uncertainty) could not be fully assessed unless stochastic modelling had been used; however, as risk inputs (infection rate, boiling practice and quantity of milk) were obtained by a random process, variability was regarded as low in the six point scale measurement (negligible, very low, low, moderate, high and very high). The data used for this study involved two factors of uncertainty: market chains in Rubaga, Makindye and Central Kampala Divisions of Kampala District, and infection rates of milk from Nakasongola-Lwero, and Kayunga-Mukono dairy production areas. The quantity of milk sold in Rubaga, Makindye and Central Kampala Divisions was estimated as the difference between (1) quantity of milk transported from production areas at the wholesale milk centres and (2) the quantity of milk sales at the milk shops purchased from the wholesale milk centres. In terms of quantity of milk, Nakasongola-Lwero, and Kayunga-Mukono production areas produced significantly smaller amount than Mbarara dairy production areas. Uncertainty was judged to be 'low'.

Considering variability and uncertainty, the degree of confidence in this risk analysis was judged 'high' using five point scale measurement (very low, low, moderate, high and very high).

7.4. Discussion

In this study, a quantitative risk analysis was conducted to assess the daily risk for populations living in urban areas of Kampala of purchasing raw milk infected with *B. abortus* during the rainy season. For the analysis, the Codex Alimentarius Commission risk assessment system (Codex Alimentarius Commission 1999) was used since the risk for marketed milk was assessed. Although the analysis used 'deterministic' modelling, all data were collected in a random process, thus the degree of confidence in the results was judged to be high. Cross-sectional studies are known to have a limitation of time variant and invariant factors (Dohoo 2004). In this study, the risk of purchasing raw milk infected with *B. abortus* per day in the rainy season of 2007 was analysed but the risk may be different in the dry season or in other years. There are reports on infection rate of milk with *Brucella*: 44.4% (72/162) of milk samples from individual animals were positive in urban and peri-urban areas of Kampala (Mwiine 2004); 15.3% (19/124) of bulk milk samples were positive in the central and southern parts of Uganda (Wakiso and Mukono districts) (Nakavuma 1994) using the Milk Ring Test (MRT). However, since the MRT can cause a high percentage of false positives (Merck Veterinary Manual. 2008), these infection rates of milk were not used as risk inputs.

The total risk of purchasing raw milk infected with *B. abortus* in urban Kampala was expressed as 0.117 (1 is the case that all unpackaged milk consumed in urban Kampala is infected with *Brucella* when purchased). Considering the hazard characteristic of human brucellosis, the risk was characterised as high. No particular spatial risk factor was found; urban populations can purchase raw milk infected with *B. abortus* at any place in urban areas of Kampala.

Exposure assessment found the most risky source of human brucellosis in urban Kampala to be milk shops with a bulk cooler. In October 2007, the Dairy Development Authority (DDA) of Uganda was promoting construction of milk shops with a bulk cooler which is the most risky source of brucellosis and was planning to ban milk sales by vendors/traders with a milk can on a bicycle by which the total risk cannot be greatly reduced. Besides, this study has revealed that milk vendors/traders with a milk can on a bicycle play an important role in the milk distribution system in urban and peri-urban areas of the Kampala economic zone. The livelihoods of these vendors/traders and milk distribution systems could be largely affected by this proposal if it is enforced. In Nairobi, public health officials are facing the same difficult decisions; whether to allow urban livestock production because of its economic benefits to urban communities, or to ban it for its public health risks (Szonyi 2008). In considering the high risk of purchasing raw milk infected with *B. abortus* shown in the present study, authorities might respond by banning urban cattle farming. However, as the present study has shown, banning urban cattle farming would not greatly reduce the risk and could severely affect the livelihoods of large number of cattle keeping households. The risk management study presented here has highlighted the best options: to construct milk boiling centres either in Mbarara dairy production areas or in peri-urban areas of Kampala, and to enforce milk traders to sell milk to these boiling centres. Construction of boiling centres is expensive, but would result in the great reduction in the risk. These options require legislation which is difficult to enforce and will affect livelihood of urban residents by the increase of retail price of milk. However, these challenges may be overcome in order to secure the food safety in Kampala. The awareness of this important public

health problem among decision makers as well as consumers thus needs to be raised by this risk analysis.

In the present study, the risk of purchasing raw milk infected with *B. abortus* was investigated - not the risk of infection with *B. abortus*. A similar probabilistic risk analysis for *Escherichia coli* O157 in Ugadna and Kenya suggested (Grace 2008), consumer practice of boiling milk before consumption can mitigate the risk of infection with *B. abortus*. During informal interviews in the present study, all respondents living in urban areas answered that they boiled milk before drinking. Similarly in Nairobi, Kenya, all urban milk consumers and nearly all rural consumers (96%) boiled milk before consumption (mainly for tea) (Arimi *et al.* 2005). However, given the large number of human brucellosis cases seen reported in a recent report (Makita 2008), consumption of undercooked or raw milk among the populations in urban areas of Kampala could be common. Therefore, the reduction of the risk of brucellosis could be indeed assisted by dissemination, through National administration system and mass media, of the results obtained from the present study.

8. Chapter 8   General Discussion

8.1. *Highlights of this thesis*

8.1.1. Characteristics of peri-urban interface of the Kampala economic zone (Chapter 2)

The first part of this thesis dealt with the peri-urban interface (PUI) of Kampala, the capital of Uganda. The heterogeneous features of PUI, which have made it difficult to determine the exact PUI, have been reported in several studies; in Kumasi, Ghana (Adam 2001), in West Africa (Drechsel *et al.* 1999), in France, (Cavailhes *et al.* 2004; Cavailhes 2004) and in Canada (Paquette & Domon 1999). Among a number of methodologies available, Rapid Rural Mapping, that classifies village units into urban, peri-urban and rural (Adam 2001), was selected for the present study to overcome the problem of heterogeneity inherent in PUI studies. The discovery of the common rule of the flow of people seen in urbanisation (Chapter 2, Section 2.3.2) helped in the development of a decision tree model for urbanicity classification which was used for determination of the characteristics of PUI in Kampala, Uganda. The computed decision tree model (Venables 2002) found that percentage of full-time farmers contributed the most to urbanicity level determination and speed of population change and source of the change followed it, but observational and agricultural information were essential to the determination. The methodology used in the present study is simple, rapid and objective and would be applicable to any other city and town in any developing country.

In the present study, Kampala was found to be expanding in a concentric fashion with its PUI distributed 12.1 km (95%CI: 10.5-13.9) from the city centroid. The PUI of Kampala was characterised by the middle range of household density, Euclidean distance from city centroid, transportation cost to Kampala Taxi Park and percentage

of full-time farming household compared with urban and rural areas. Provision of electricity and piped water supply was found to be the best indicator of the PUI in Kampala, which was consistent with another study in India (Hunshal 1997). To start with determination of the PUI, obtaining maps of electricity or piped water supply can be useful to estimate the spatial distribution of peri-urban areas of any city in any developing country.

8.1.2. Characteristics of urban and peri-urban agriculture (Chapter 3)

LC1s classified into urban, peri-urban and rural were compared for their agricultural characteristics to determine the possible risks of zoonotic disease transmission and the dependency of urban and peri-urban populations on agricultural activities for food security.

The risks of zoonoses were discussed from two viewpoints, firstly in terms of animal density/human density and secondly in relation to market chains. In terms of animal density/human density, the zoonotic risks from direct or close contacts were estimated to be lower in urban areas for all livestock species than in peri-urban and rural areas, with the one exception of broilers where the risks are highest in peri-urban areas. Zoonotic risks from poultry were the highest among animal species, in terms of animal density/human density, due to the popularity of chicken keeping in and around Kampala. The risk of the infection with H5N1 highly pathogenic avian influenza (HPAI) in urban and peri-urban populations in Kampala was clearly very high and it could pose a serious health problem. In relation to market chains,

zoonotic risks were high in dairy milk, pork and goat meat due to weak regulation of hygiene interventions.

Urban and peri-urban agriculture (UPA) were clearly important for food security in Kampala, particularly crops and indigenous breed chicken in urban and peri-urban areas. UPA also had a significant role in income generation. Slum dwellers were not dependent for their food on agriculture but preferred to work at jobs in town where they could earn a living. Farming in urban areas is technically illegal or regulated by zoning in Kampala City (Ssemwanga 2002); however, if UPA were to be encouraged by changes in the relevant legislation, this would be likely to enhance the food security and contribute to poverty reduction of the inhabitants.

8.1.3. Zoonotic diseases affecting human populations in urban and peri-urban areas of Kampala (Chapter 4 and 5)

The present work was the first study in Kampala, Uganda designed to screen all zoonotic diseases affecting urban and peri-urban populations by means of analysis of medical records. Using these records, the most important zoonotic diseases in and around Kampala were found to be *M. bovis* tuberculosis, brucellosis, cysticercosis, and gastrointestinal (GI) infections. Among these diseases, brucellosis was the most significant zoonotic disease; a great number of patients were serologically diagnosed positive.

Abdominal TB, brucellosis, epilepsy and GI infections, which probably represent the

most important zoonotic disease risks in urban and peri-urban Kampala, were investigated for spatial risk factors using case-control studies; abdominal TB and epilepsy were selected to study the risks of *M. bovis* tuberculosis and cysticercosis respectively and fracture was selected as a control disease. Using spatial scan statistics (Kulldorff 1997), spatial clustering including Mulago Hospital, of which medical records were used for the present study, was observed for brucellosis, epilepsy, and GI infections but no clustering was noted for abdominal TB. These disease clusters were thought to be statistically confounded by the 'catchment area' of Mulago Hospital for outpatients; the source registry for medical records of brucellosis, epilepsy and GI infections was outpatient record whilst that of abdominal TB and fracture data was derived from inpatient record. However, these results should be interpreted with caution as the disease clusters included some slum areas close to Mulago Hospital which included the concentration of brucellosis, epilepsy, GI infections and abdominal TB cases; these cases are most likely to have been associated with low levels of hygiene in these areas. Level of urbanicity was not associated with the incidence of abdominal TB, brucellosis, epilepsy and GI infections and the present study could find no highly significant factor for incidence of these diseases. However this does not mean that the risks were negligible; rather the risks of the most important zoonotic diseases might be homogenously high in urban, peri-urban, and rural areas of the Kampala economic zone. It must be noted that the size of urban population is far larger than that of peri-urban and rural areas in the Kampala economic zone, i.e. the urban population was at the greatest risk.

8.1.4. Prevalence of brucellosis in cattle in urban, peri-urban and rural areas of the Kampala economic zone (Chapter 6)

The goal of this work was to develop a risk model for milk infected with *Brucella abortus* in urban areas of Kampala given the great number of human brucellosis cases (652 serologically positive cases from June 2004 to May 2006, Chapter 4, Section 4.3.3.2). 177 cattle dairy farms were randomly selected in urban, peri-urban and rural areas of Kampala for brucellosis studies. Using buffered plate agglutination test (BPAT) (Nielsen 1979) and competitive enzyme-linked immunosorbent assay (CELISA) (Gall 1998), the prevalence of brucellosis in milking cows at the herd level was found to be 6.2% (95% CI: 2.7-9.8) and at the individual animal level 5.0% (95% CI: 2.9 – 7.0) in urban and peri-urban areas of the Kampala economic zone.

The risk factors for brucellosis at the herd level were found to be free-range farming and abortion. Keeping cattle in the northern parts of peri-urban and rural areas of the Kampala economic zone was a spatial risk factor. All the herds infected with *B.abortus* were located in the areas and the herds with identified risk factors were also concentrated in the areas. All the large herds of which the majority kept cattle free range and a half was infected with *B. abortus* were located in the northern part. A few zero-grazing dairy herds were infected with *B. abortus* although they were not large-scale or free-range. Level of urbanicity, use of bulls for insemination or cattle age was not found to be risk factors. A history of cattle being bought-in was not a risk factor for brucellosis suggesting that the endemic status of brucellosis in and around Kampala might be maintained indefinitely but at low herd prevalence. Surprisingly vaccination was not a preventive factor for brucellosis infection. S19 vaccine, which might be used in Uganda, is known not to perfectly protect animals

from *B. abortus* infection (Bagnat 2002; Moryon 2004). This study suggested that for the control of brucellosis in cattle, owners of free-range cattle farms and zero grazing dairy farms should be encouraged to vaccinate animals against brucellosis using RB51 vaccine (Moriyon 2004) which has shown to be more effective.

The results of interviews with dairy cow keepers revealed that a large quantity of milk infected with *B. abortus* is produced in peri-urban and rural areas, especially northern parts of Kampala, and distributed to the urban areas of Kampala and consumed together with locally produced milk. However the spatial risk might not be restricted in the northern parts of Kampala because milk infected with *B. abortus* might be distributed from larger dairy production areas outside Kampala and Chapter 7 examines this.

8.1.5. Risk analysis for purchase of milk infected with *Brucella abortus* in urban areas of Kampala (Chapter 7)

A quantitative risk analysis was conducted to (i) assess the daily risk for populations living in urban areas of Kampala of purchasing raw milk infected with *B. abortus* during the rainy season and (ii) to identify the best options for control of human brucellosis in urban areas of Kampala. The milk distribution model was developed based on interviews with milk sellers in 48 randomly selected urban LC1s and the risk was calculated using this model and the test results of milk samples obtained from these sellers using the indirect enzyme-linked immunosorbent assay (IELISA) for brucellosis (Gall 2002). The quantity of infected and non-infected milk yields in

urban and peri-urban areas of Kampala obtained from the cattle survey (Chapter 6) was also used as a risk input for the risk model.

The total risk of purchasing raw milk infected with *B. abortus* in urban Kampala was proportionally expressed as 0.117 defining the situation that all unpackaged milk consumed in urban Kampala is infected when purchased as risk 1. Considering the harmful characteristics of human brucellosis, the risk was characterised as high. No specific spatial risk factor could be identified. However it is clear that urban dwellers can purchase raw milk infected with *B. abortus* anywhere in the urban areas of Kampala. Exposure assessment found the most risky source of human brucellosis in urban Kampala to be milk shops with bulk coolers. This risk management study has highlighted the best options for controlling brucellosis which would be to construct milk boiling centres either in Mbarara dairy production areas - the main milk production area in Uganda (Bernard *et al.* 2005), or in peri-urban areas of Kampala and to ensure that milk traders to sell milk to these boiling centres. This would be a costly exercise and would require legislation which would be difficult to enforce and also will affect livelihood of urban residents by the increase of retail price of milk. However, these challenges may be overcome in order to secure the food safety in Kampala. The awareness of this important public health problem among decision makers as well as consumers thus needs to be raised by this risk analysis.

8.2. Outlook

Many studies have recognized the importance of urban agriculture in Kampala and usually recommended such activities be permitted in suitable locations, with appropriate policy support to ensure environmental sustainability (Davidson 1994; Kimeze 2005; Musimenta 1997; Nostrand van 1994; Nuwagaba 2002).

However, urban and peri-urban agriculture (UPA) has benefits and drawbacks: it contributes to the livelihoods of urban and peri-urban populations but can also damage their health. In the present study in the Kampala economic zone, the roles of UPA including livestock farming in food security and income generation were clearly highlighted. However, the risks of contracting food borne zoonotic diseases were also found to be high.

In the present study, a quantitative risk analysis for brucellosis, the most significant zoonosis in Kampala, could be used to present control options including efficacy, cost and feasibility. The outcome of this risk analysis could be extrapolated to help in controlling all milk borne zoonotic diseases, including for example *M. bovis* tuberculosis, in Kampala. Moreover, this methodology of risk analysis in market chains could be applied for other foods of livestock-origin in Kampala as well as for other cities and towns in other countries. Were control programmes to be carried out based on these risk analyses for the most important zoonotic diseases, the health of urban and peri-urban dwellers in Kampala would be greatly improved and poverty level reduced.

Cities are rapidly expanding in all developing countries and urban areas of Kampala

will continue to expand and the peri-urban interface (PUI) will continue to move outwards. The methodologies used in this thesis, based on surveys at the village level, could be used in future research projects to update information on urban and peri-urban agriculture and risks of zoonotic diseases in Kampala. Regular monitoring would be a driving force for enhancement of food hygiene in the growing Kampala economic zone.

8.3. Follow-up studies

A stochastic risk modelling for purchase of milk infected with *B. abortus* in urban areas of Kampala could give more confidence in the presentation of effective control options. The present work has also shown that the following studies would be profitable: identification of *M. bovis* from TB patients/milk/cattle carcasses using molecular technology; epidemiology of cysticercosis in humans and pigs using CT scans and serology; identification of zoonotic GI infections patients by culturing and molecular technology; epidemiology of the identified GI infections pathogens in the causal livestock species; risk analyses for food borne zoonotic diseases in the market chains other than brucellosis. A risk analysis for HPAI would also be useful to prepare Uganda for possible outbreaks.

However, risk analysis will not be completed unless risk communication is carried out. Risk assessment on its own will not be effective unless the knowledge gained is disseminated to the population at risk which would require involving local and national government, mass media and consumers as well as research scientists.

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Appendix I

<u>Village Characteristic Survey (VCS) Questionnaire</u>

For the project of
Urban and Peri-urban Livestock Farming in Uganda
University of Edinburgh and Makerere University

Name of interviewer (Title)	
Date and time	
District	
Sub-county	
Parish (LC2)	
Village (LC1)	
Place of interview	
GPS Reading and number	North (N)+: No: East (E) : Altitude :
Names of informant (Title), Relations to the village, Years of residence (>3)	
Observational features	

Village Characteristics (* For researcher use)

Types	Urban	Peri-urban	Rural	Urban slum
Reasons				

<u>Section A: Life in your village</u>

This section is about the life in the village. Please tick or write the answer.

1.   What is the total number of households?

2.   How many households are engaging agriculture in full-time bases?

3.   How much money does it take to go to Kampala city centre?

By bus:

By minibus

By public taxi:

By bodaboda (motorcycle):

By bodaboda (bicycle):

Other transportation (please explain):

4.1.   What is the name of nearest trading centre? | |

4.2.   How much money does it take to go to the trading centre?

By public taxi:

By bodaboda (motorcycle):

By bodaboda (bicycle):

Other transportation (please explain):

If you can go on foot, how much time does it take you? | |

5.   Were there recent improvements (since 2000) of following public facilities in your village?

      If yes, when were they?

Road light

  Yes □   No □   When was it? | |

Piped drinking water supply

  Yes □   No □   When was it? | |

Sewage pipe (closed)

  Yes □   No □   When was it? | |

Sewage pipe (opened)

  Yes □   No □   When was it? | |

Waste collection service

  Yes □   No □   When was it? | |

6.   How many shops, kiosks and places are there in your village? Where are they?

  The shops sell fresh milk bag in refrigerator | | | |

  The shops sell fresh milk bag without refrigerator | | | |

The shops sell packed milk in refrigerator		
The shops sell packed milk without refrigerator		
The shops sell cold soda		
The shops sell fresh milk in bulk cooler		
Milk man with bicycle		
Butcheries with refrigerator		
Butcheries without refrigerator		
Live chicken market		
Livestock market		
Cattle, goat abattoirs		
Pig abattoirs		
Local slaughter places for cattle and goat		
Local slaughter places for pig		

7.1. How many ongoing land disputes are there in your village between agriculture and non-agriculture use? ⬚

7.2. How many ongoing land disputes are there in your village between old resident and new comer? ⬚

8. How many these schools are there in your village?

Public primary school	
Private primary school	
Public secondary school	
Private secondary school	

9. Do you feel any problems of human waste recently? If yes, what kinds of problems and how much do you feel?

⬚

Section B: Agriculture
    This section is about agriculture in your village.

1. How many households keep local cattle? ⬚
    Among them, how many households sell them to Kampala? ⬚
    Or how many households sell them to local abattoir? ⬚
    If there are, please give the name of abattoirs. ⬚

How many households keep local cattle more than 50?

If there are, please give their names.

2. How many households keep cattle for milk?

Among them, how many households have exotic or cross cows?

How many households keep exotic cows more than 10?

If there are, please give their names.

How many households sell milk to Kampala?

Or where to, how, and how many households sell milk?

3. How many households keep pigs?

Among them, how many households sell them to Kampala?

Or how many households sell them to local abattoir?

If there are, please give the name of abattoirs.

How many households keep sow pigs more than 10?

If there are, please give their names.

4. How many households keep sheep?

Among them, how many households sell them to Kampala?

Or how may households sell them to local abattoir?

If there are, please give the name of abattoirs.

How many households keep sheep more than 20?

If there are, please give their names.

5. How many households keep goats?

Among them, how many households sell them to Kampala?

Or how may households sell them to local abattoir?

If there are, please give the name of abattoirs.

How many households keep goats more than 30?

If there are, please give their names.

6. How many households keep local chicken?

7. How many households keep broilers?

Among them, how many households sell them to Kampala?

Or how may households sell them to local trading centre?

If there are, please give the name of trading centre. ⬜

How many households keep broilers more than 500? ⬜

If there are, please give their names. ⬜

8. How many households keep layers? ⬜

   Among them, how many households sell eggs to Kampala? ⬜

   Or how may households sell them to local trading centre? ⬜

   If there are, please give the name of trading centre. ⬜

   How many households keep broilers more than 500? ⬜

   If there are, please give their names. ⬜

9. How many hatcheries are there? ⬜

   If there are, please give their names and places. ⬜

10. How many households grow tomato? ⬜

    Among them, how many households sell them to Kampala? ⬜

    Or how may households sell them to local trading centre? ⬜

    If there are, please give the name of trading centre. ⬜

    How many households grow tomato in more than 10 acre land? ⬜

    If there are, please give their names. ⬜

11. How many households grow matoke? ⬜

    Among them, how many households sell them to Kampala? ⬜

    Or how may households sell them to local trading centre? ⬜

    If there are, please give the name of trading centre. ⬜

    How many households grow matoke in more than 10 acre land? ⬜

    If there are, please give their names. ⬜

12. How many households grow maize? ⬜

    Among them, how many households sell them to Kampala? ⬜

    Or how may households sell them to local trading centre? ⬜

    If there are, please give the name of trading centre. ⬜

    How many households grow maize in more than 10 acre land? ⬜

    If there are, please give their names. ⬜

13. How many households grow rice? ⬜

    Among them, how many households sell them to Kampala? ⬜

Or how may households sell them to local trading centre?

If there are, please give the name of trading centre.

How many households grow rice in more than 10 acre land?

If there are, please give their names.

14.   How many households grow vegetable?

Among them, how many households sell them to Kampala?

Or how may households sell them to local trading centre?

If there are, please give the name of trading centre.

How many households grow them in more than 10 acre land?

If there are, please give their names.

Section C: Health Service

These are questions about hospitals and clinics. Please answer these questions.

1.   How many these hospitals or clinics are there in your village? What are these names? If not, how long (minutes or hours) does it take to go to nearest one?

National hospital: By _____   How long? _____

District hospital: By _____   How long? _____

Mission hospital: By _____   How long? _____

Muslim hospital: By _____   How long? _____

Health centre: By _____   How long? _____

Private dispensary: By _____   How long? _____

NGO dispensary: By _____   How long? _____

Private clinic: By _____   How long? _____

NGO clinic: By _____   How long? _____

Private pharmacy: By _____   How long? _____

2.   Which hospital or clinic people usually go when they are sick?

3.   If you have enough money, which hospital or clinic do you go when you are sick?

Please answer the name(s).

Why do you choose it?

4.   If you are sick seriously, where do you go? Why do you choose it?

Thank you very much for your cooperation.

Appendix II

The R code used for Generalised Linear Model with binomial errors to produce fitted prediction and 95% confidence interval lines of the relationship between proportion of LC1s having the facilities and the distance from city centroid of Kampala

```
## copy this function and paste unchanged into R from here
lines.predict.lm <- function(object,x=NULL,plot.pred=FALSE,...) {
   if (!plot.pred) object <- object[,-1]
   matlines(x,object,...)
}

bbpredict.glm <-
function(object,...,level=0.95,se.fit=TRUE,type=c("link","response","terms")
,
                        interval=c("none","confidence","prediction"),
                        mc=FALSE,mcsamp=1000) {
   interval <- match.arg(interval)
   type <- match.arg(type)
   if (interval=="none")
return(predict.glm(object,...,se.fit=se.fit,type=type))
   if (type=="terms") stop("can't combine type='terms'
and interval!='none'")
   linkinv = family(object)$linkinv

   ## need result on link scale to calculate conf int

   p1 = predict.glm(object,...,se.fit=TRUE,type="link")
   tfrac <- abs(qt((1 - level)/2, object$df.residual))
   p1.ci = tfrac*outer(p1$se.fit,c(-1,1))+p1$fit
   p2 = cbind(p1$fit,p1.ci)
   colnames(p2) = c("fit","lwr","upr")
   if (interval=="confidence") {
```

```
    if (type=="response") p2 = linkinv(p2)
    p3 = p1
    p3$fit = p2
    if (!se.fit) p3$se.fit <- NULL
    return(p3)
  }
  ## want prediction intervals: have to do a bit more work -- actually,
  ## quite a lot since there are not (?) closed-form quantiles for
  ## the lognormal-Poisson and logit-normal-binomial.   What I have
  ## done in the past is to get the prediction intervals
  if (type=="link") stop("can't combine type='link' and
interval='prediction'")
  levels <- c((1-level)/2,1-(1-level)/2)
  fam <- object$family$family
  if (fam=="binomial") {
    size <- rowSums(object$model[[1]]) ## how general is this?
  }
  fitresp = predict.glm(object,...,type="response")
  if (!mc) {
    warning("bogus prediction intervals -- don't include parameter
uncertainty")
    if (family =="poisson") {
      p1.ci = sapply(levels,qpois,lambda=fitresp)
    } else if (fam=="binomial") {
      p1.ci = sapply(levels,qbinom,prob=fitresp,size=size)
    }
  } else {
    warning("Monte Carlo prediction intervals")
    n <- length(object$residuals)
    mod <- model.matrix(object$formula)   ## careful with data= ??
    require(MASS)
    parvals = mvrnorm(mcsamp,mu=coef(object),Sigma=vcov(object))
    if (fam=="poisson") {
      predvals = apply(parvals,1,
        function(rpars) {rpois(n,lambda=linkinv(mod%*%rpars))})
    } else if (fam=="binomial") {
      predvals = apply(parvals,1,
```

```
          function(rpars) {rbinom(n,prob=linkinv(mod%*%rpars),size=size)})
      }
      p1.ci = t(apply(predvals,1,quantile,levels))
   }
   p2 = cbind(fitresp,p1.ci)
   colnames(p2) = c("fit","lwr","upr")
   return(list(fit=p2))
}


lines.predict.glm <- function(object,
                              x=NULL,
                              plot.pred=FALSE,...) {
   object <- object$fit
   if (!plot.pred) object <- object[,-1] ## remove fitted value
   matlines(x,object,...)
}
### to here – without any change in the code between these two points.


## below are an example
> water<-read.csv(choose.files())
> attach(water)
> names(water)
[1] "distance" "sample"    "count"
> p<-count/sample
> y<-cbind(count,sample-count)
> model7<-glm(y~distance,family=quasibinomial,data=water)
> summary(model7)
> paw<-bbpredict.glm(model7,interval="confidence",type="response")
> paw
>     plot(distance,p,pch=16,cex=1.3,axes=FALSE,xlab="Distance    from    city
centroid",ylab="Proportion    of    villages    with    piped    water
supply",xlim=c(0,20),ylim=c(0,1),frame.plot=TRUE)
> axis(side=2)
> axis(side=1,at=c(1,3,5,7,9,11,13,15,17,19),lab=c(1,3,5,7,9,11,13,15,17,19))
>lines(distance,p,lty=2)
> lines.predict.glm(paw,x=distance,lty=c(1,3,3),plot.pred=TRUE)
```

Appendix III

The Cattle Farm Questionnaire

Date: _____   Name: _____
Time: _____   Age: _____
District: _____   Type: _____
Sub-county: _____   GPS point: _____
LC1: _____   N _____
Sample number: _____   E _____

Question	Answer	Remarks
Number of cattle (Cows, calves, bulls and heifers) and Cattle breeds		
Quantity of milk (L/day) Dry season Rainy season		
Destination of sales and means (truck, bicycle, direct)		
Do you boil milk before selling? Or do traders boil milk?		
Where do you buy cattle from?		
Price of milk		
Abortion		
Brucellosis vaccination		
Brucellosis diagnosis or undulant fever		

September 2007, Kohei Makita, University of Edinburgh

Appendix IV

The Milk Shop Questionnaire

Date: _____

Time: _____   Type: _____

District: _____   Name: _____

Sub-county: _____   GPS point: _____

LC1: _____   N _____

Sample number: _____   E _____

Question	Answer	Remarks
Where do you buy the milk from? and How many litres do you buy a day?		
How many days do you work?		
Do you test milk when you buy? What kind of test?		
Do you boil milk before selling? Do you buy boiled milk? If yes, where milk was boiled?		
What are the methods of transportation?		
Time of transportation?		
Price?		
Where are customers from?		