The Spatial distribution of Tsetse (Diptera: Glossinidae) within the *Trypanosoma brucei rhodesiense* focus of Uganda.

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Declaration

I declare that all research within this thesis is my own work and that the thesis was entirely composed by me. The work has not been submitted for any other degree or professional qualification.

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Albert .W.Mugenyi

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While acknowledging all the above, it is especially important to state that my first family (Maldin, Rodney, Sydney and Elaney) was supportive of this work and made a lot of sacrifices. To my brothers and sisters…thank you all thank you everybody!!

Abstract

One of the greatest problems for sub-Saharan Africa is shortage of epidemiological data to support planning for provision of adequate public and animal health services. The overriding challenge is to provide the necessary resources to facilitate the process of regular data collection in support of disease surveillance and vector monitoring across target regions. Due to such circumstances, there is currently an increasing interest towards devising cheaper but yet significantly reliable means for availing the needed epidemiological and vector data for planning purpose. This study comes as a contribution towards solving such challenges.

The study has three research components starting with a review of past Uganda national tsetse and trypanosomiasis control efforts as a means towards appreciating the dynamics of controlling the vector and disease. This is an analysis of what was applied, what worked, what didn't, and why it didn’t as linked to the broader vector and disease control system.

Secondly through the use of remote sensing, geographical information systems and global positioning technologies tsetse species were sampled within Lake Victoria Basin. Only two species of tsetse were trapped, *G. f. fG. f. fuscipes* which was widely distributed across the surveyed area, and *G. Pallidipes* which was detected in a few isolated locations close to the border with Kenya in Eastern Uganda. The analysis of land cover with tsetse findings showed an important association between *G. f. fuscipes* and particular vegetation mosaics. Unfortunately, while the results are highly informative, approaches for data collection such as this one are costly and unlikely to be sustained by the already over-burdened health systems in the low developed countries of Africa.

The third and main part of this study investigates, demonstrates and delivers the possibilities of applying spatial epidemiological modelling techniques to produce both tsetse distribution and abundance maps. Four spatial and non-spatial regression models (Logistic, Autologistic, Negative binomial and Auto-negative binomial), were constructed and used to predict tsetse fly presence and tsetse fly abundance for the study area. The product is an improved understanding of association between environmental variables and tsetse fly distribution/abundance and maps providing continuous representations of the probability of tsetse occurrence and predicted tsetse abundance across the study area.

The results indicate that tsetse presence and abundance are influenced differently. Tsetse abundance is highly determined by river systems while tsetse presence is majorly influenced by forested landscapes. Therefore, efforts to control trypanosomiasis through vector control in the Lake Victoria basin will call for delineation of such clearly identified high tsetse accumulation zones for targeted tsetse control operations. This will ensure optimum utilization of the scarce resources and above all contribute to the protection of humans and animals against trypanosomiasis infection.

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Abbreviations

AU	African Union
AUC	Area under curve
AU-IBAR	African Union International Bureau for Animal Resources
AVHRR	Advanced very high resolution radiometer
CEVA	Asante Animale Veterinary pharmaceutical company
COCTU	Coordinating office for control of trypanosomiasis in Uganda
DE	District Entomologist
DFID	Department for international development (UK)
DHO	District Health Officer
DVCO	District Vector Control Officer
DVO	District veterinary officer
EATRO	East Africa Trypanosomiasis Research Organisation
EEC	European Economic Commission
ESA	European Space Agency
EU	European Union
FAO	Food and Agriculture Organisation of the United Nations
FEWSNET	Famine early warning systems network
FITCA	Farming in tsetse controlled areas
GIS	Geographic Information Systems

GOU	Government of Uganda
GPS	Global positioning system
GTZ	German technical assistance
HAT	Human African Trypanosomiasis
IAEA	International Atomic Energy Agency
IR	Incidence ration
IKARE	IK Aid and Relief Enterprise
LSHTM	London school of hygiene and tropical medicine
LSTM	Liverpool school of tropical medicine
MAAIF	Ministry of Agriculture Animal Industry and Fisheries
MOH	Ministry of Health
NALIRRI	National Livestock Resources Research Institute
NDVI	Normalized difference vegetation index
NSSCP	National sleeping sickness control programme
OAU	Organisation of African Unity
OAU/IBAR	Organisation of African Unity- International Bureau for Animal Resources
ODA	Overseas Development Administration
OR	Odds Ratio
PAAT-IS	Plan against African Trypanosomiasis – Information system

PATTEC	Pan African Tsetse and Trypanosomiasis eradication campaign
RAP	Restricted application protocol
ROC	Receiver Operating Characteristic
SAT	Sequential Aerosol Technique
SIT	Sterile Insect Technique
SOS	Stamp Out Sleeping Sickness
SRTM	Shuttle Radar Topography Mission
SSTC	Sleeping Sickness Treatment centres
STATFA	Sustainable Tsetse and Trypanosomiasis Free areas
UNCDF	United Nations Capital Development Fund
UNDP	United Nations Development Programme
USAID	United States Agency for International Development
WB	World Bank
WHO	World Health Organisation

Dedication

This work is dedicated to my late parents (Patricia and Isaac Mugenyi) who sacrificed and provided the necessary foundation. Wherever they are resting I am pretty sure they are happy with this achievement. Unfortunately you were both unable to live to physically witness this triumph. With God's guidance I pledge to make use of this award to fulfil what both of you wished me to do for humanity. REST IN PEACE.

CHAPTER 1: INTRODUCTION

1.1 Background

Trypanosomiasis is a vector-borne disease known to be transmitted by the tsetse fly (WHO, 2012; Simaro et al. 2011) and spatially distributed within the sub-Saharan Africa (Cecchi, 2009). Its maintenance is determined by the interrelationship of three elements: vertebrate host, parasite and the vector responsible for transmission (Leak, 1998; Welburn et al. 1999). This disease affects both humans and animals. In humans, the disease is referred to as human African trypanosomiasis (HAT), locally known as *sleeping sickness*. In animals the disease is called animal African trypanosomiasis (AAT), also locally referred to as *nagana,* a name derived from a Zulu term meaning "to be in low or depressed spirits".

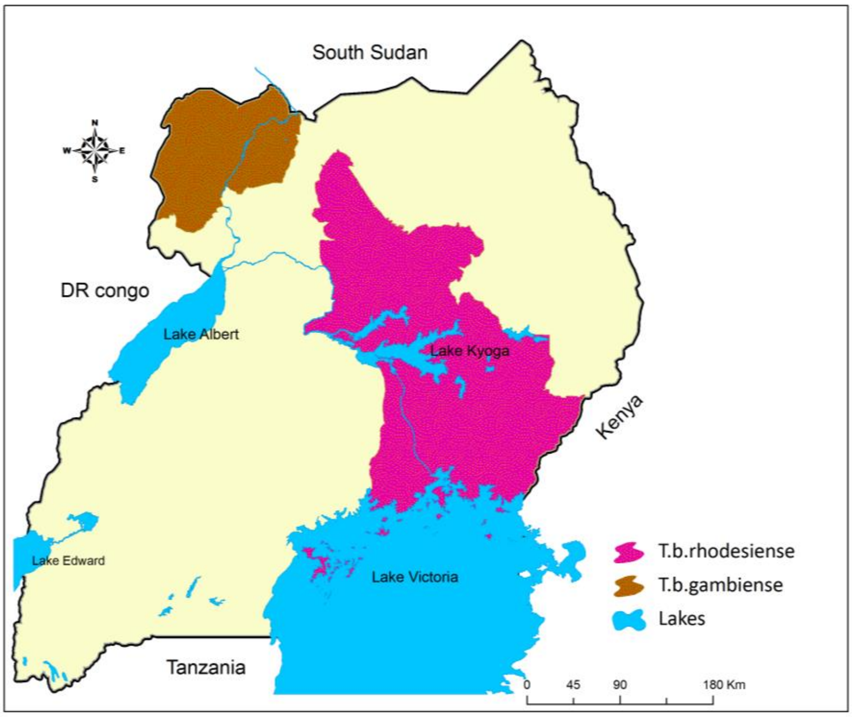


Figure 1 Spatial distribution of sleeping sickness in Uganda (2014)

In Uganda, HAT is encountered in two major foci which are, the West Nile region with *Trypanosoma brucei gambiense* (*T.b.gambiense*) and the south east region with *Trypanosoma brucei rhodesiense (T.b.rhodesiense) (*Welburn et al. 2001a; Simaro et al. 2010). However, over the last 10 years, the *T.b.rhodesiense* has been spreading to new areas creating a concern for a possible merger of the two forms of the disease over time (Batchelor et al 2009). Currently the two disease foci are separated by less than 100km (NSSCP Report 2012) as shown in figure 1. About 11 million people in Uganda are at risk of contracting HAT, where on average, 300-350 HAT cases are reported each year (WHO, 2012).

AAT is one of the most significant constraints to livestock production in Uganda (MAAIF report 2011). It is widespread throughout the tsetse infested areas of the country with an average prevalence of 4.5% recorded in cattle in the trypanosomiasis endemic areas (STATFA project report, 2011). AAT affects all types of livestock except poultry. Since over 70% of the country is tsetse infested, approximately 60% of the national livestock (i.e. cattle, goats and sheep) is exposed to the risk of AAT (MAAIF report 2011).

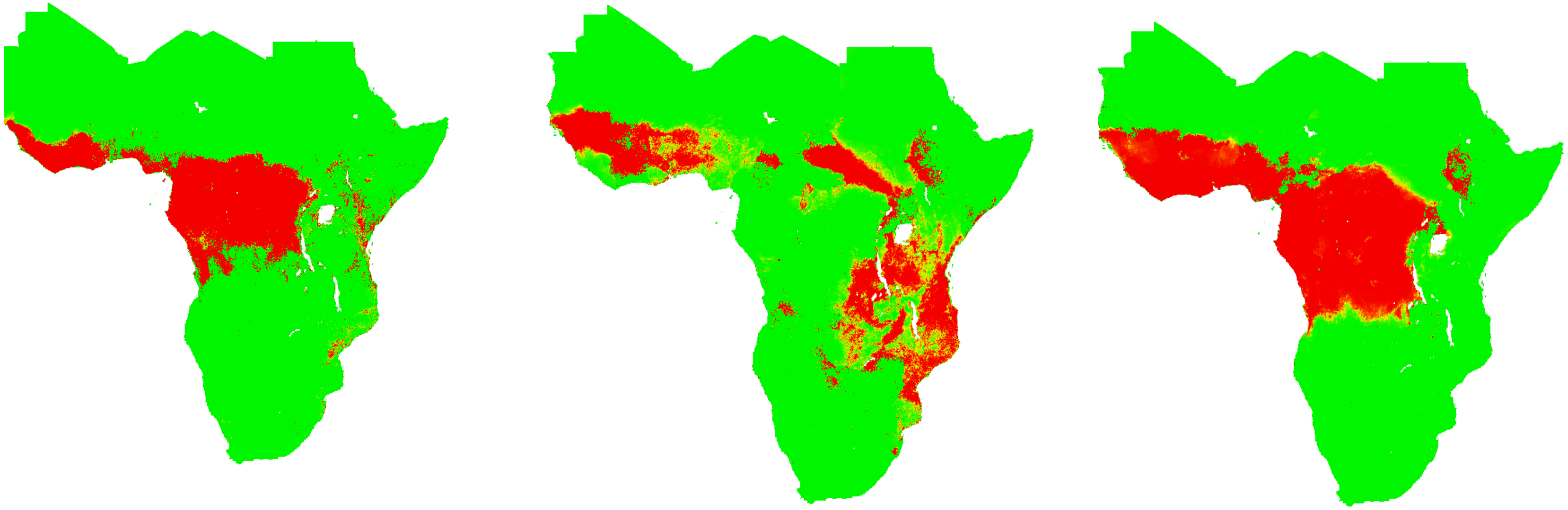
This study is a product of an identified need to cheaply monitor tsetse fly populations against a series of control interventions, climate change and land-use changes. Due to the nature of the support, tsetse control interventions are usually not sustained, leading to tsetse re-infestation. This situation has largely been assumed to be responsible for the persistent AAT and frequent HAT outbreaks in different parts of Uganda. Besides, there is growing concern for the establishment of factors favouring the current spread of HAT to new areas, including vector presence and abundance (Batchelor et al 2009). This work sets out to review existing knowledge on tsetse vector presence and adopts a modelling approach with outputs that can guide decision-making.

Currently, as shown in figure 2, tsetse are assumed to be present in 75% of the Sub Saharan zone of Africa. This implies that 75% of the Sahel zone has been rendered significantly and potentially inaccessible to primary producers, largely the rural livestock farmers. This situation puts the life of both humans and livestock living in tsetse infested areas at risk (Leak, 1998, Welburn et al. 1999).

It is estimated that a total of 34 species and sub-species occupy the vast African land mass, most of which overlaps with zones of habitation. Tsetse flies, based on morphology and habitat biodiversity, are categorised into three groups i.e. *Morsitans, Fusca* and *Palpalis* (Rogers & Robinson 2003). Due to a scarcity of resources, the true picture of the actual species diversity and definition of spatial extents of tsetse infested areas remain unknown (Berrang-Ford and Garton, 2013). The absence of such information presents a challenge to national efforts to plan for disease prevention through vector control (Wint, 2001).

In Uganda, historical maps show that there are 13 sub-species with only nine documented. These include; *Glossina fuscipes fuscipes (G. f. fuscipes)*, *Glossina pallidipes (G. Pallidipes)*, *Glossina morsitan submorsitans (G.m.submorsitan)*, *Glossina morsitan centralis (G.m.centralis), Glossina fuscipes congolensis (G.f. congolensis, Glossina fucipleuris (G.fucipleuris), Glossina longipennis (G.longipennis), Glossina brevipalpis (G.brevipalpis)* and *Glossina n.hopkinsi* (*G.n.hopkinsi)*. However, disease prevalence has been attributed to *G.m.submorsitans* in the West Nile region where *T.b.gambiense* is present while *G. f. fuscipes* and *G. Pallidipes* accounts for the spread of *T.b.rhodesiense* in south east and central Uganda (Ford and Katondo, 1977b).

This study takes advantage of and builds on existing modelling knowledge with recently acquired point-based tsetse datasets to generate sub-national level tsetse distribution maps for the target regions of Uganda. Beyond direct decision support, such outputs have been used in spatial analysis models to enable the understanding of spatial linkages between location-specific sleeping sickness cases / nagana and the vector.



(a) *Fusca* group *(b)* *Morsitans* group *(c)* *Palpalis* group

Figure 2 (a-c) Predicted distributions of tsetse in Africa.

Maps prepared using data from: PAAT-Information System - ERGO Ltd and TALA (2000).

Mapping the vector can assist in the computation of the tsetse vector burden. This in turn will serve the core purpose of accurately guiding tsetse and trypanosomiasis control interventions in the country.

1.2 Problem statement

Current trypanosomiasis control efforts have been largely determined and driven by observed disease outbreaks in the disease foci (COCTU report 2010). Due to geographical position, Uganda uniquely has both forms of HAT. The acute form (*T.b.rhodesiense*) occurs traditionally in the south east focus while the chronic form (*T.b.gambiense*) occurs in the North West part of Uganda. Unfortunately, the distance between these two foci is getting shorter and shorter as reflected by the new cases detected in new areas of the country (Ministry of Health report 2011; Picozzi et al. 2005a). The convergence of these two forms of disease is considered a public health problem of continental concern (Berrang-Ford and Garton 2013). Several factors have been identified as being associated with the disease advance and spread, notably, uncontrolled livestock movement across the region coupled with high tsetse fly densities (Wardrop et al. 2010).

There is a need to understand the distribution of the trypanosomiasis transmitting vectors and their actual apparent densities across the country, primarily within the two foci zones. Existing tsetse abundance knowledge is scant and available data are associated with low precision. Most planning and tsetse control efforts have been based on the historical maps of tsetse flies *(Glossina Spp)* distribution in Africa (Ford and Katondo, 1977) and until more recently, the FAO/IAEA predicted tsetse presence or absence maps (Wint 2002) - (STATFA project report, 2011). The use of out-dated maps as a decision support presents challenges in the quest to break the trypanosomiasis transmission chain (Moore et al. 2010) due to constant tsetse habitat encroachment by man. Amidst scarce resources, there is a need to devise means for obtaining reliable up-to-date tsetse information across target areas, preferably through applying modelling techniques. This is the purpose for which this study is set out.

1.3 Conceptual framework

This study was based on a conceptual framework for vector modelling as a decision support to pest control (Rogers, 1991&2000; Hendrickx et al. 2001; Wint & Rogers, 2000; Moore & Messina, 2010; Robinson et al. 1997; Rogers & Randolph, 1993). It comes as a response to the critical need for provision of up-dated tsetse distribution data that can be used in the planning of trypanosomiasis control interventions. The study provides key outputs regarding the likelihood of tsetse presence / absence and tsetse apparent densities to the scale of 1km resolution based on spatially differentiated environmental variables.

The methodology developed can be used to inform decision-making on the tsetse vector situation in the target area based on a set of covariates. By providing information on the status of tsetse presence / absence under the different environmental conditions throughout the year, the study provides an opportunity for the decision-maker to accurately select and target tsetse control options. Knowing where the tsetse fly concentrations exist during any intervention season, will simplify the field operations as one will know where to effectively deploy. As a result the scarce or limited resources will be utilised optimally.

As opposed to several vector models in the literature, this study carries along with it the advantage of using abundant tsetse catch data derived from over 5000 geo-referenced tsetse trap sites uniformly spread over the study area. The model outputs so generated do not necessarily guarantee solutions to the problems linked to tsetse flies, but the ideas and scenarios therein will form the basis for focused attention. Decisions towards addressing the problem will be taken with a higher level of certainty.

1.4 Research objectives

1. To investigate and evaluate the past tsetse and trypanosomiasis control efforts in Uganda since 1960.
2. To design and apply a systematic grid-based approach for entomological field data capture.
3. To determine and map the relative distribution of different tsetse species within the study area based on the results of the point-based tsetse catches.
4. To predict tsetse fly presence / absence in the study area.
5. To predict tsetse fly abundance / apparent densities within the study area.
6. To better understand the relationship between environmental / climatic factors and tsetse presence / abundance?

1.7 The Tsetse fly

1.7.1 What is a tsetse fly?

A tsetse fly (*Genus Glossina*) is one type of fly that appears greyish/ brownish in colour (Leak, 1999). It has one pair of wings and while at rest the wings overlap (i.e. the wings completely fold so that one wing rests directly on top of the other over the abdomen). Its mouth parts (proboscis) as shown in figure: 3, point directly forward and feeds on blood predominantly. Its length (adults) ranges from 8 to 17 mm. Several species and sub-species of *Genus Glossina* exist within sub-Saharan Africa. However, only six of them are considered responsible for the transmission of pathogenic human parasites causing *T.b.rhodesiense* and *T.b.gambiense.*

Figure 3 Photo of a feeding tsetse fly

Efforts to characterise tsetse fly locations and their apparent density can inevitably help in explaining the persistence of HAT and AAT in an area. Low tsetse apparent density is usually associated with reduced transmission of trypanosomiasis, and *vice versa*. Unfortunately, in some situations due to a variety of factors at play, this assertion my not necessarily be correct.

1.7.2 Tsetse life cycle

Tsetse flies live in areas that provide ideal conditions for every stage of their life cycle. Precisely, tsetse flies live in habitats that provide shade for developing puparia and resting sites for adults (Rogers, 2003). Tsetse are characterised with a low reproductive rate giving birth to one larva by the mature female adult after one to nine days of egg deposition in the uterus. The larva burrows into the ground from where it pupates within a few hours without any feeding at all. The pupa transforms itself into a live adult fly from beneath the soil layer after 30 days (Leak, 1999). The adult fly takes 12-14 days to mature in preparation for mating. Like most of insects, tsetse flies have a life cycle which is constituted by four major stages (i.e. egg, larva, pupa and adult). The key difference is that for the tsetse fly, the egg is simply deposited and held in the uterus of the mother fly until it is converted into a larva. It is the larva that is released from the mother fly and buries itself in the sub-soil. The process of converting from larva into pupa is done within the sub-soil. The pupa will hatch into an adult and then exit the sub-soil onto the surface. This entire process takes close to 50 days in total (Leak, 1999). Understanding the life cycle of the tsetse fly is key to the development of national / sub-national tsetse control interventions. Efforts need to be put at the weakest stage in the lifecycle considering the tools available.

1.7.3 Tsetse Biology and Ecology

Tsetse flies are a class of insects that are very sensitive to environmental changes and ecological instability (Terblanche 2008). This implies that tsetse flies are found in ecologically suitable habitats which have the necessary temperature; humidity and vegetation cover (Leak, 1999; FAO, 1982). Generally, tsetse thrives best in areas with mean annual temperatures of 19 - 30^{o}C. Temperatures below 19^{o}C will slow down tsetse activity and general physiology (Terblanche, 2008). Such unfavourable conditions will prevent the tsetse from flying and carrying out normal life functions. The tsetse will be unable to move to find a host for a blood meal, leading to its starvation (Hargrove, 1980). Under extreme temperatures of below 10^{o}C, tsetse will die within 3 hours of exposure (Rogers, 2003).

1.7.4 Tsetse Species

The spatial distribution of tsetse species (*Fusca, Palpalis* and *Morsitans)* has been estimated to cover a wide part of sub-Saharan Africa (Figure: 2). These species groups are distinguished based on the construction of the male genitalia (FAO, 1982). The three groups of tsetse flies live in different types of habitat. According to Rogers (2003), the *palpalis* group (subgenus Nemorhina) occupies riverine habitats throughout Africa. With one exception (*G.longipennis*), the species of the *fusca* group (subgenus *Austenina*) are forest flies inhabiting either rain forest or isolated patches of forest, along with riverine forest in the savannah zones. The *morsitan* group prefers open woodland, forest edges and scattered thickets. The dominant sub-species in Uganda is *G. f. fuscipes* and is part of the *Palpalis* group (Wint, 2001).

Table 1 Tsetse flies: Continental species and sub-species

Species Group	Sub-species	Preferred habitat
Fusca	1. *Glossina nigrofusca nigrofusca* 2. *Glossina nigrofusca hopkinsi* 3. *Glossina fusca fusca* 4. *Glossina fusca congolensis* 5. *Glossina fuscipleuris* 6. *Glossina haningtoni* 7. *Glossina schwetzi* 8. *Glossina tabaniformis* 9. *Glossina nashi* 10. *Glossina vanhoofi* 11. *Glossina medicorum* 12. *Glossina severini* 13. *Glossina brevipalpis* 14. *Glossina longipennis*	These are forest flies inhabiting either rain forest or isolated patches of forest, along with riverine forest in the savannah zones
Palpalis	1. *Glossina palpalis palpalis* 2. *Glossina palpalis gambiensis* 3. *Glossina fuscipes fuscipes* 4. *Glossina fuscipes martinii* 5. *Glossina fuscipes quanzensis* 6. *Glossina tachinoides* 7. *Glossina pallicera pallicera* 8. *Glossina pallicera newsteadi* 9. *Glossina caliginea*	These are found mainly in gallery forests, swamps and in watersides with closed canopy
Morsitans	1. *Glossina langipalpis* 2. *Glossina pallidipes* 3. *Glossina morsitans morsitans* 4. *Glossina morsitans submorsitans* 5. *Glossina morsitans oentralis* 6. *Glossina swynnertoni* 7. *Glossina austeni*	These are found in open woodland and woodland savannah, but they are found also in forest edges, scattered thickets

Source: Tsetse training manual, FAO 1982

1.7.2 Tsetse species and sub-species in Uganda

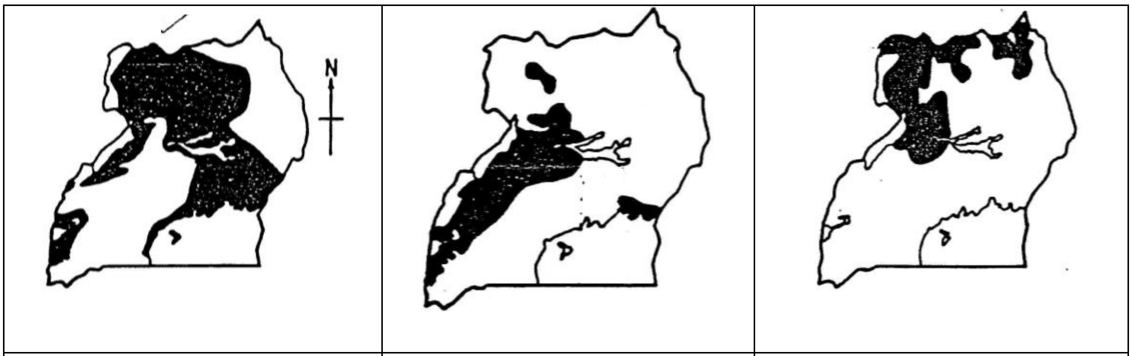
There are currently eleven tsetse sub-species of Glossina in Uganda. Unfortunately, only two of them have received significant verification and publicity; these are; *G. f. fuscipes* and *G. Pallidipes*. This could be attributed to their wide geographical presence in many parts of Uganda, including their significant role in trypanosomiasis transmission. The different national categories and sub-categories are provided in Table: 2.

Table 2 Tsetse flies: National species and sub-species

***Fusca* group**	***Palpalis* group**	***Morsitans* group**
1. *G. longipennis*, (Corti 1895) 2. *G. fusca congolensis*, (Newstead and Evans 1921) 3. *G. brevipalpis*, (Newstead 1910) 4. *G. nigrofusca, hopkinsi* (Van Emden 1944) 5. *G. medicorum*, (Austen, 1911) 6. *G. fuscipleuris,* (Austen, 1911)	*G. fuscipes fuscipes,* (Newstead 1910)	1. *G. morsitans centralis,* (Machado 1970) 2. *G. morsitans submorsitans,* (Newstead 1910) 3. *G. morsitans submorsitans*, ugandensis Vanderplank 1949,(Machado 1970) 4. *G. pallidipes*, (Austen 1903)

Currently, *G. f. fuscipes* is the sub-species of major economic importance transmitting both HAT and AAT in Uganda. According to the available tsetse fly distribution maps figures 4,5,6,7 & 8, *G. f. fuscipes* is the most abundant and widespread constituting close to 70% of the country's total tsetse infested area. *G. Pallidipes* covers about 20% of the country (42,000 km^2), while *G.m.submorsitans* occupies approximately 19% of the country (35,000 km^2). This trend of species colonisation is not static due to constant human interference with the tsetse natural habitats. Increasing human population in terms of settlement and agricultural land expansion leads to loss in tsetse habitats. This implies that inevitably the flies have to migrate to new areas (habitats) or perish.

Existing records show that tsetse flies are widely distributed in Uganda. The few places without tsetse are associated with extreme annual temperatures of either below 15^{0}C or above 35^{0}C. These include high altitude zones along mountains Elgon, Rwenzori and Moroto, and the Kigezi highlands.



a) *G. f. fuscipes*

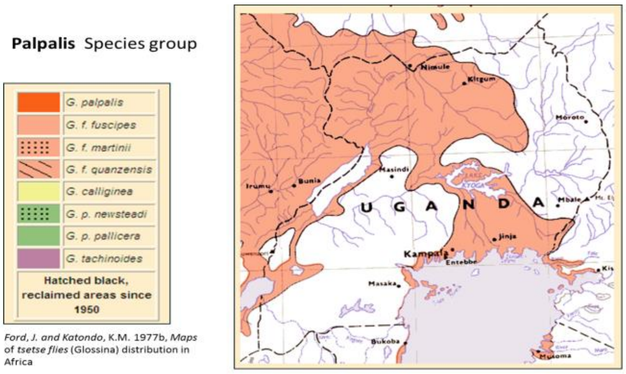
b) *G. PallidipesG. Pallidipes*

c) *G.m.submorsitans*

Figure 4: Historical distribution of the three major tsetse species

Source: *Tsetse control Department archives (MAAIF)*

At continental level, *G. f. fuscipes* is estimated to occupy much of central Africa predominantly. At a national scale, *G. f. fuscipes* is known to be present in several parts of Uganda, with a geographical extent stretching from Lake Victoria shores through central Uganda up to the West Nile region. In addition, *G. f. fuscipes* is also traced around Lakes Albert, Edward and George in western Uganda (Figure: 4 and Figure: 5). The islands of Kalangala and Buvuma located within Lake Victoria, have also been identified as having *G. f. fuscipes* (Tsetse control Department–Maps,1982; Okoth, 1991; Wint, 2001; Ford & Katondo, 1977b).



Ford, J. and Katondo, K.M. 1977b, *Maps of tsetse flies* (Glossina) distribution in Africa

Figure 5: Ford.J. and Katondo Tsetse distribution map (1977) PALPALIS

Source: http://www.sleeping-sickness.ird.fr/cartes -accessed 12/01/2012

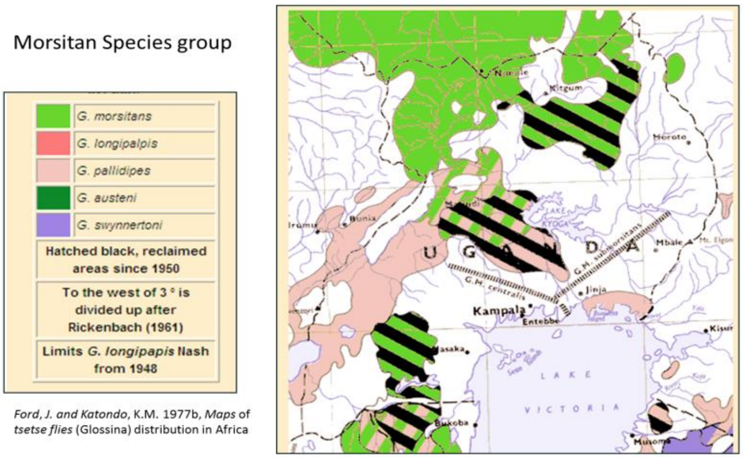


Figure 6: Ford.J. and Katondo Tsetse distribution map (1977) MORSITAN

Source: http://www.sleeping-sickness.ird.fr/cartes -accessed 12/01/2012

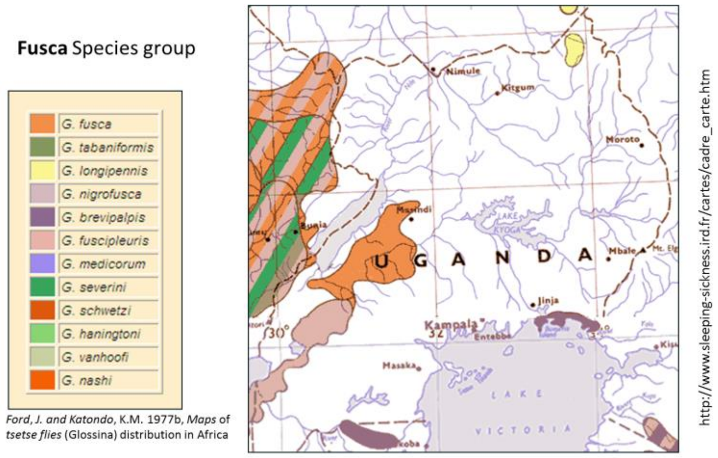


Figure 7: Ford.J. and Katondo Tsetse distribution map (1977) FUSCA

Source: http://www.sleeping-sickness.ird.fr/cartes -accessed 12/01/2012

1.8 The tsetse problem in Uganda

Tsetse infestation negatively impacts on human health, livestock production and productivity and limits land utilization (Shaw et al. 2013 & 2014; Schofield & Kabayo 2008). There are 11 sub-species of tsetse belonging to the Genus of Glossina in Uganda (Table; 2). The most predominant tsetse sub-species is the *G. f. fuscipes* which is currently the known vector responsible for both HAT and AAT. Other important species, in Uganda, responsible for the transmission of AAT include; *G. Pallidipes*, and *G.m.submorsitans*. Over 140,000 Km^2 of the land surface of Uganda is infested with tsetse flies; ranging from low to medium and high levels of infestations. Areas of most high tsetse fly infestation include; Kalangala and Buvuma Islands; where an average of 200 tsetse flies, per trap per day have been recorded (Entomology report-MAAIF-2008). Similar situations exist in the districts located along the Lake Victoria shores. Inland, in the south eastern region, dense fly populations are confined to the river banks of the Nile and its tributaries; around the Lake Kyoga area in the Teso and Lango sub-regions (Figure: 8). The large tsetse populations follow the River Nile course up to South Sudan. The whole of the Northern, the North West and Karamoja regions have high infestations as well. Tsetse catches of between 60 and 160 flies per trap per day are quite common (Entomology report-MAAIF-2008). The Mid central and parts of South west Uganda have low populations of tsetse, but higher infestations of other nuisance livestock biting flies which can also transmit animal trypanosomiasis mechanically. The Kabale and the Sebei regions (Figure: 8) are the only known areas not having any tsetse infestation on record. This is largely due to the intensive humanised landscape and cold climate experienced in the two regions due to high altitudinal index.

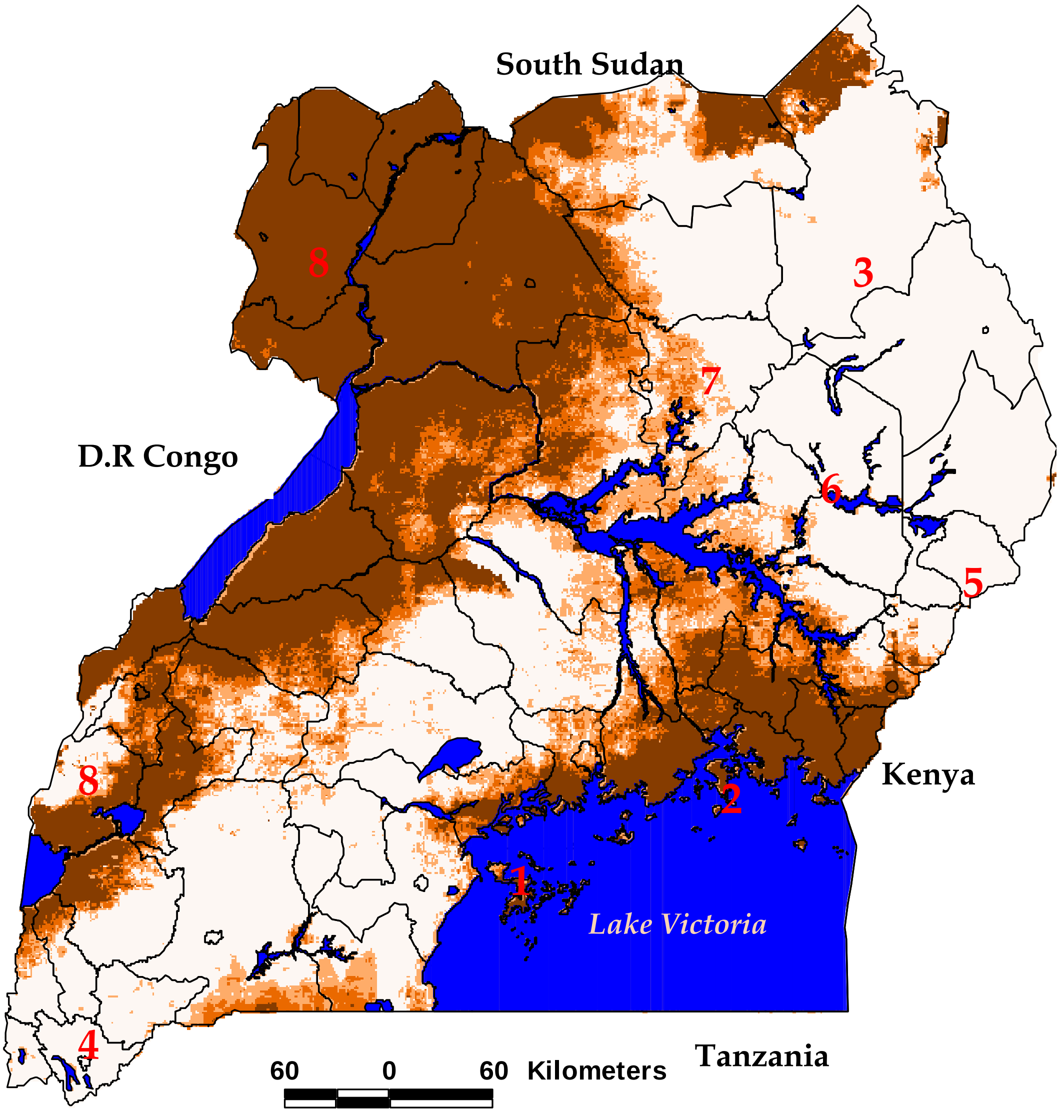


Figure 8: Tsetse prediction for the three major species combined in Uganda (Wint, 2001)

Area names

1. Kalangala Island
2. Buvuma Island
3. Karamoja region
4. Kabale region / Kigezi highlands
5. Sebei region / Mt. Elgon region
6. Teso region
7. Lango region
8. West Nile region
9. Mt. Rwenzori region

1.9 Tsetse fly distribution and trends of tsetse fly mapping in Uganda

Tsetse distribution maps are crucial in the control and management of human and animal trypanosomiasis in the country. Accurate maps are based on high precision data derived from field investigations. In the absence of such data, many scholars and researchers have constructed tsetse maps using partial district level entomological reports, existing publications, sector reports and land cover suitability studies. Due to continuous human interference with the natural habitat and overall climate change, the tsetse belts have been known to change over time (Cecchi et al 2008). This implies that maps ought to be updated regularly.

Rogers & Robinson (2003) assert that, 'the first continental estimates of the distribution of tsetse were compiled and published in 1954 by W.H Potts, based on individual records dating back to Austin in 1903 and on territorial maps of colonial surveys prepared between 1947 and 1951'.

Historical Uganda tsetse distribution maps were generated in 1971 (Ford and Katondo, 1971) as a first edition based on entomological data collected in the 1960s. These were subsequently revised as tsetse distribution maps (Ford and Katondo, 1973, 1975, 1977 & 1984). Based on updated information at the time, most especially the discovery of Glossina *nashi* Potts (1955) in Gabon, more maps were further revised (Moloo, 1985). The Moloo maps of 1985 may be categorised as the most recent in the series of historical tsetse maps. Unfortunately, details of the extent of coverage, procedures and processes applied in map revisions are not readily available in the common public domain.

According to historical maps, Uganda is approximately 80% tsetse infested. This percentage is derived from the constructed tsetse fly belts which inevitably contain more than one tsetse species and with fuzzy ground level boundaries. For mapping purposes such boundaries are identified using physical and biological barriers (Ford & Katondo, 1977).

Until 2001, Uganda had largely been relying on the historical Ford and Katondo tsetse distribution maps as a means of reference for tsetse control operations. These maps had, from time to time, been validated using isolated district level tsetse survey results (Entomology report-MAAIF-2008). The tsetse prediction maps produced by FAO (Wint, 2001) provided a relief in terms of planning nationwide tsetse interventions. Fortunately, under the PATTEC project (2006-2011), data has been collected and were used to generate some fine resolution tsetse distribution maps covering approximately 40,000 km^2 of the Lake Victoria basin, primarily the *T.b.rhodesiense* region. Once completed and made available, these will appear as the most recent and reliable sub-national tsetse datasets for Uganda.

1.10 Past tsetse and trypanosomiasis control strategies

Most control strategies were initiated and implemented by the central government. Key strategies included; bush clearing (total and selective), game elimination through hunting, game eviction, cattle evacuation, maintenance of tsetse pickets, application of insecticide on cattle, and ground spraying using Dieldrin-3% insecticide (Kangwagye, 1975). These interventions were geared towards either removal of the tsetse habitat or direct killing of the tsetse flies themselves. While these interventions had significant impact on creation of tsetse free zones at the time, the approaches, especially those involving bush clearance and game elimination, caused environmental degradation (Sserunjoji 1973 &1976; FAO 1993). Hence, they have since been discontinued due to environmental concerns.

During the period 1950-1970 an approximate ground area of 15,000 km^2 of greater Ankole region (Isingiro, Nyabushozi and Mitoma) in south western Uganda, was freed of tsetse flies using bush clearance and game elimination methods. The tsetse free zone created, had suitable conditions for large scale livestock keeping and, thus, led to the establishment of the Ankole / Masaka ranching scheme on part of the reclaimed land. The project code-named tsetse elimination and ranching development project was designed as a planned progression from unoccupied fly-infested area to profitable and productive ranching covering an area of 1500km^2 of ranches, plus 50km^2 of land for pasture investigation (at Muko) and beef breeding at Ruhengere Field station (Kangwagye 1975). This project co-financed by government and USAID, was implemented in the counties of Bukanga, Isingiro, and Nyabushozi of greater Ankole region and Kabula plus Mawogola of then Masaka district. The scheme comprised of over 100 ranches.

For most of the early 1900s disease management in both humans and livestock was controlled through treatment of animals and people with clinical symptoms of trypanosomiasis (Mbulamberi 1989; Okello-Onen et al. 1994; Okiria 1985). In some instances there was evacuation of population at risk of disease contraction. To break the transmission cycle, humans had to be shifted from areas of high tsetse infestation to areas of low or no tsetse infestation.

In the last two decades, emphasis has been put on the use of insecticide treated tsetse traps and livebait technology which is the application of insecticide on livestock to act as moving traps. Treatment of livestock to cleanse them of trypanosomes, combined with active screening of human population by medical personnel was a common practice in HAT endemic areas. Such approaches reduced sleeping sickness incidence in south eastern Uganda by as much as 92.8% between 1988 and 1993. A corresponding reduction of 94% in the apparent tsetse density of the vector (*G. f. fuscipes),* was also observed (Programme development document-Uganda, 2002). Most of these successful tsetse interventions have been carried out under 'project conditions', with substantial funding. Unfortunately, sustaining achievements in most cases has been a great challenge since projects are usually short-lived.

1.11 Trypanosomiasis

1.11.1 Human African trypanosomiasis (HAT)

HAT (Sleeping sickness), a tsetse transmitted disease, is mainly a problem of poor rural populations who primarily depend on their land and labour for livelihood (Welburn et al 2006; Waiswa 2006; Simaro 2010; Shaw 2013; Berrang-Ford et al 2006; Allsop 2001; Fevre et al. 2008b). The disease affects all age groups especially the most productive age group of 15-45 years and is 100% fatal if not treated (WHO 2012, Simaro 2012, NSSCP report 2011). A significant proportion of children are also affected by this disease. Unfortunately, many of these children even after successful treatment will usually have a considerable delay in their mental development, which will impact on their school results and professional performance (NSSCP report 2011). Infected individuals are weakened often for many years, which sinks them into further poverty as they are unable to work. The World Health Organization (WHO, 2012) estimates that in Africa 300,000 – 500,000 people are infected with sleeping sickness annually and according to a WHO report (2012), 70 million people are at risk of contracting the disease.

With respect to Uganda, there is eminent danger that *T.b.rhodesiense* and *T.b.gambiense* might overlap in the near future leading to co-occurrence of the two diseases. While there may be chances of people being infected by both types of the disease, the key medical challenge will exist along the process of identifying which specific type of disease individuals may be are infected with. Treatment of individuals with co-infection of both the acute and chronic forms of sleeping sickness is expected to be complicated (Fèvre et al 2001, Welburn et al 2001a; Maudlin 2006).

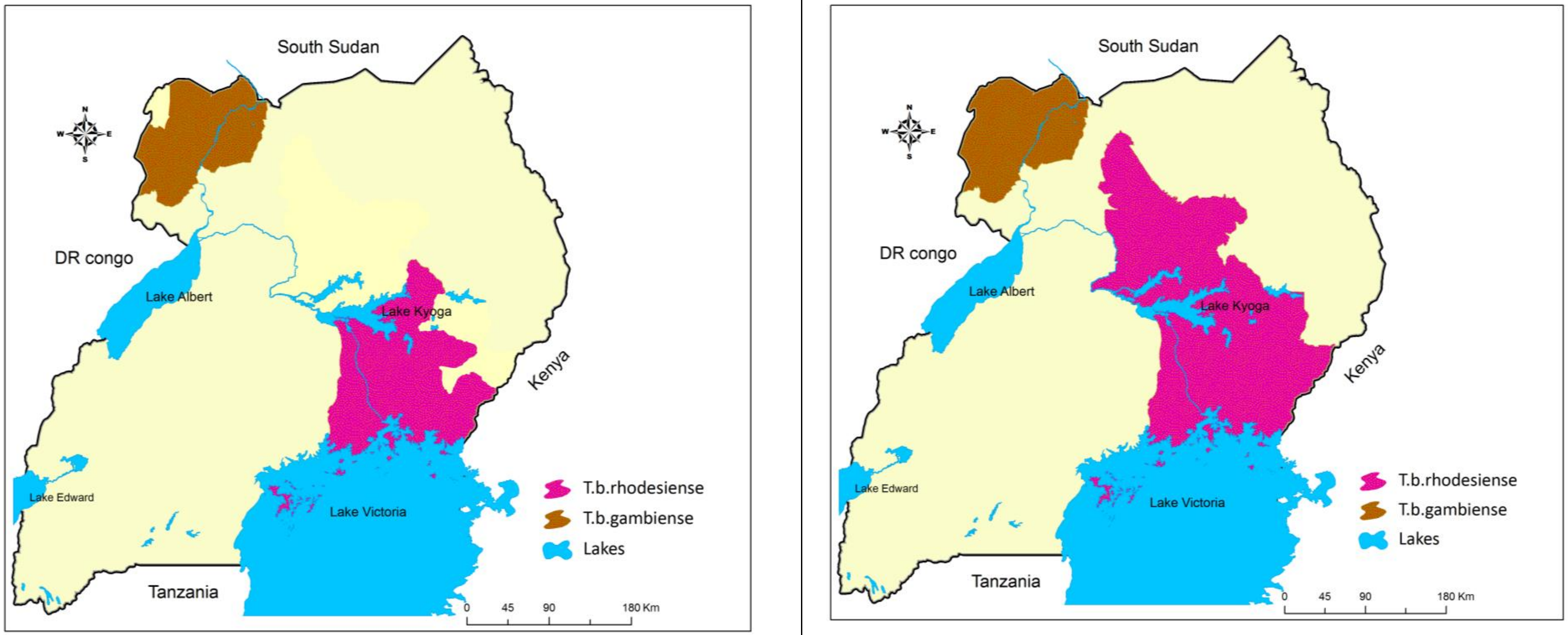
There is a high level of HAT under-reporting of up to 40% in Uganda (Odiit et al. 2005). Unreported cases are not treated and certainly result in death and it is estimated that for every one reported death of HAT case, 12 deaths (92%) are unreported (NSSCP report 2013). The average cost of managing a HAT patient per household is estimated at US $163 (NSSCP report 2013). This cost represents 43% of the annual revenue of a household estimated at US $384 and based on agricultural production and small scale trade (NSSCP report 2013). Livestock movement across regions has also contributed to the spread of the disease (Fevre et al. 2006). The most common symptoms of HAT include; (i) presence of the chancre which is a primary lesion that develops at the site of the tsetse bite, recurrent fevers, oedema of the face, general skin rash, enlarged-painless cervical lymph nodes in the posterior cervical triangle, and in later stages (ii) mental, locomotion and overall sleep disturbances (WHO 2012; Kennedy, 2005).

1.11.2 Spatial distribution of human African trypanosomiasis (HAT) in Uganda

The distribution of HAT in Uganda is linked to the endemic districts located within the two foci i.e. West Nile and South-east regions (Ford, 1971). The *Trypanosoma brucei gambiense* endemic districts of West Nile include; Arua, Koboko, Maracha, Adjumani, Moyo and Yumbe. While, the *Trypanosoma brucei rhodesiense* South East focus endemic districts include; Bugiri, Kamuli, Kaliro, Kayunga, Busia, Mayuge, Iganga, Mukono, Jinja, Pallisa, Soroti, Tororo, Dokolo, Kaberamaido, Lira, Kalangala and Namutumba. Current evidence shows that the disease continues to spread to new districts outside the traditional sleeping sickness territory (Berrang-Ford et al. 2006). The maps shown in figure 9 show the expanded area under HAT coverage from 2000 to 2012. The progressive expansion is more on the *T.b.rhodesiense* from south east focus extending northwards. The *T.b.gambiense* focus appears to be more stable with very limited progression over the 12-year period.

Significant HAT impact was first felt in the Busoga region in 1940 (Berrang-Ford et al 2006a & 2006b). During this time a total of 274 deaths were registered within a period of three years only. The disease was presumably imported from northern Tanzania by immigrant labourers (Kangwagye et al. 1987). During the 1960s, HAT had reached elimination levels in Uganda. Between 1960 and 1970, the two main HAT foci in Uganda were in West Nile and South eastern Uganda, particularly in Busoga and Bukedi provinces (Mbulamberi, 1989).

As observed from the graph (Figure: 10), the period between 1975 - 1983 witnessed the highest number of sleeping sickness cases. This was an outbreak of *T.b.rhodesiense* in south-eastern Uganda (Busoga region) and was suspected to have been attributed to political / economic instability which caused indiscriminant movement of people and livestock across the traditional trypanosomiasis corridor (Mbulamberi, 1989). The outbreak spread to nearly all districts in Busoga (Iganga, Kamuli, Jinja) and part of Bukedi (Tororo) and Buganda (Mukono) (Enyaru et al. 1992). The period 1985-1992 was another outbreak of *T.b.rhodesiense*, with 1987 as being the peak with 6674 cases (Berrang-Ford et al 2006).



(a) 2000

(b) 2012

Figure 9: (a-b) Spatial distribution of Sleeping Sickness within endemic areas of Uganda for 2000 and 2012

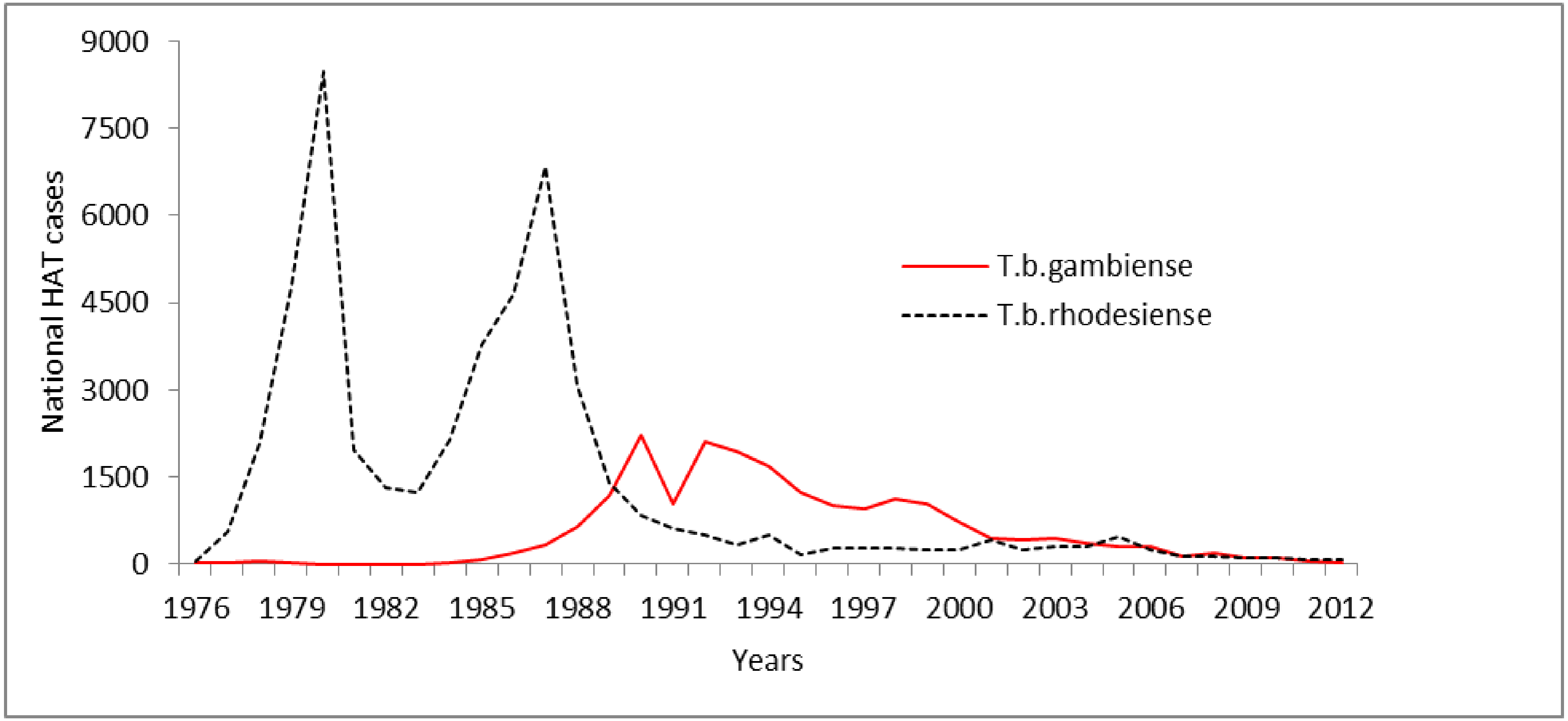


Figure 10: Trends of sleeping sickness (HAT) in Uganda (1976 – 2012)

1.11.3 Animal African trypanosomiasis (AAT)

Animal African trypanosomiasis commonly known as *Nagana* is one of the most significant constraints to livestock production in Africa (Shaw 2014; Cecchi 2009; Jordan, 1986; Kristjanson, 1998). The disease is presumed to be widely spread across the tsetse-infested territories of sub-Saharan Africa, with over 60million cattle at risk of AAT infection in Africa (Cecchi 2009). The disease presents a number of symptoms, the common ones being; blood deficiency (Anaemia), intermittent fever, edema, loss of weight, abortion and infertility among infected livestock (Taylor & Authie 2004; Leak, 1998).

AAT causes both direct and indirect losses to livestock owners at herd level. The direct losses are due to mortality, morbidity, infertility and costs of trypanosomiasis control (drugs, chemicals, tsetse traps etc). The indirect losses are due to the risk of the disease and these include: reduced food production due to reduced draught power, reduced livestock production levels due to restricted grazing and exclusion of ruminant production from tsetse infested areas. (Shaw et al. 2014; Kristjanson, 1998).

1.11.4 Spatial distribution of AAT in Uganda

AAT in livestock is presumed to be widespread throughout the tsetse infested areas in Uganda with an average national prevalence of 4.5% (STATFA project report 2012). The true picture of AAT spatial distribution for the entire country remains a challenge as no comprehensive national disease survey is known to have been conducted. However it is estimated that approximately 55 – 60 % of livestock (6.3 million head of cattle, 2.4 million goats and 2 million sheep) is exposed to the risk of animal trypanosomiasis with about 40% of these in the high-risk areas (UBOS 2008). Isolated AAT surveys carried out in tsetse infested areas indicate prevalence rates ranging from 2 to 40% (STATFA report 2011). Even areas like Karamoja (North-east Uganda) which had been previously considered low risk have since been confirmed to have bovine trypanosomiasis with a prevalence rate of up to 10% (Asaku et al. 2012).

1.12 Tsetse and Spatial epidemiology

1.12.1 Spatial epidemiology

Epidemiology is the science that studies the patterns, causes, and effects of health and disease conditions in defined populations. Thus, spatial epidemiological analysis involves a description of spatial patterns, identification of disease clusters and explanation or prediction of disease risk (Pfeiffer et al, 2008). According to Paul Elliott and Daniel Wartenberg (2004) spatial epidemiology is the description and analysis of geographic variation in disease with respect to demographic, environmental, behavioural, socioeconomic, genetic, and infectious risk factors. New analytical methods coupled with better approaches in disease data collection have enhanced the role of spatial epidemiology at national and sub-national levels. Mika (2004) contends that spatial epidemiology helps to describe the spatial variation in disease incidence for the formulation of aetiological hypotheses and to identify areas of unusually high risk in order to take preventive action.

1.12.2 Determination of presence of vector

The presence of a vector in any given area is usually determined by conducting field surveys using prescribed entomological survey tools (FAO, 1992 & 1993). Vector presence in any given area is directly affected by environmental variables most especially; temperature, humidity and vegetation cover. Such conditions influence the fly movements, reproduction and feeding behaviour among the tsetse flies. Therefore, the process of determining vector presence and selection of survey tools ought to take full consideration of environmental conditions and seasonality. However, it is critical to note that zero tsetse catch in a trap does not necessarily mean absence of tsetse flies in a given area. This could merely be a result of applying methods of low sensitivity during field surveys. Typically, mapping of very low tsetse density zones remains as a challenge as the tools used in surveys may consistently fail to catch any flies amidst scanty presence of tsetse flies (Torr et al. 2006; Adam, 2010), leading to wrong conclusions. Otherwise, where vector data has been successfully sampled, such data can be modelled with respective environmental variables to inform about the un-sampled areas (Rogers, 1991, 2000; Hendrickx et al. 2001; Wint & Rogers, 2000; Moore & Messina, 2010; Robinson et al. 1997; Rogers & Randolph, 1993).

1.12.3 Tsetse and environmental variables

Generally, the major drivers of tsetse fly habitation are temperature, humidity, rainfall, vegetation and the presence of a source of blood, mostly reptiles (FAO, 1982). Tsetse flies are a class of insects that are very sensitive to environmental changes and ecological instability. This implies that tsetse flies are found in ecologically suitable habitats which have the necessary temperature, humidity and vegetation cover (Leak, 1999). Environmental variables are important in determining; feeding behaviour, infection rates, fly movements, fly density, species-diversity and reproduction among the tsetse flies (Rogers 1996; Leak 1999).

Country-wide, Uganda experiences average temperatures of 15-28^{0}C for most of the year. The average rainfall ranges between 600 to 2000 mm per annum. The countryside is well endowed with a variety of environmental resources like; streams / rivers, swamps, lakes, forests, croplands, grasslands, woodlands, highlands, soils etc.

Unfortunately, such ideal conditions come along with a variety of life threatening aspects to the settled communities. The conditions attract and sustain the existence of a variety of disease transmitting vectors in the area. Within the study region, there is variation in vegetation cover, relief, rainfall and temperature. The impact of this variation is observed in the distribution pattern of the various life threatening vectors like tsetse flies and mosquitoes.

1.12.3.1 Rainfall

The Lake Victoria basin experiences a bi-modal type of rainfall. This is by virtue of its geographical position. The climate experienced in the Lake Victoria basin is determined by the conditions of the Inter-Tropical Convergence Zone (ITCZ). All global lands falling within 15^0 North and South of the Equator are affected by the ITCZ. Thus, the Victoria basin has two rainfall peaks around April and September each year.

Figure: 11 shows the long-term monthly average rainfall distribution for the Lake Victoria basin. The lowest amount of average rainfall is experienced in the month of June/July while the highest is in the month of April. The rainfall peaks emerge with amounts of 193 mm in April and 166 mm in November.

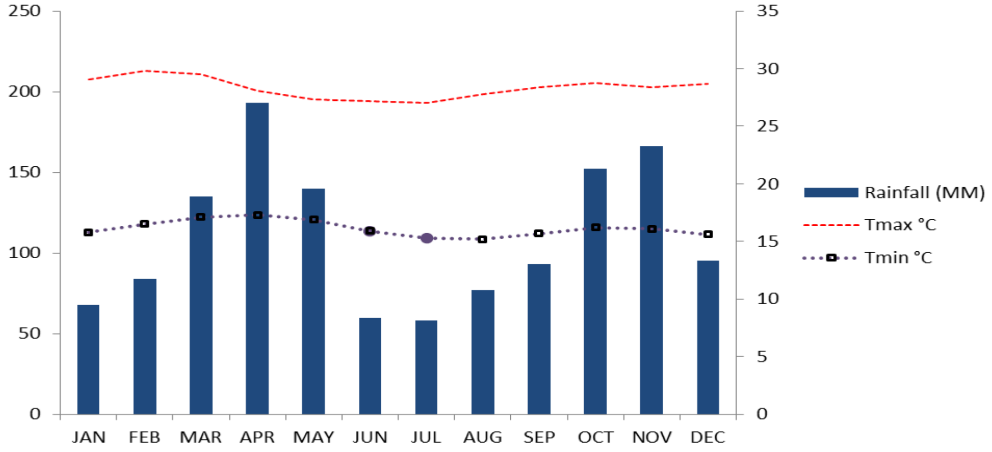


Figure 11: Long-term rainfall and temperature graph for study area
Source: Meteorological department-Kampala

1.12.3.2 Temperature

The Lake Victoria basin has a small temperature range. Temperatures range from an average minimum of 15.2° C to an average maximum of 29.8° C. Long term fluctuations in temperatures for the basin are as shown in Figure: 11.

Generally, tsetse thrive best in areas with mean annual temperatures of 19-30^{o}C. Temperatures below 19^{o}C will slow down tsetse activity and general physiology (Terblanche 2008). The tsetse will be unable to move to find a host for a blood meal, leading to its starvation (Hargrove 1980). Similarly, the tsetse insect is severely affected by high temperature conditions. Precisely, tsetse flies exposed to a temperature of more than 36^{o}C will have a 50% chance of dying within 3 hours of exposure. At a temperature more than 40^{o}C the survival capacity is close to zero (Torr and Hargrove 1999). A temperature variation of plus-minus 5^{o}C from both acceptable extremes (19 – 30^{o}C), will force the tsetse to devise a means of survival. For instance, under such conditions, tsetse will seek refuge in dull cool environments presented within tree trunks, exposed tree barks, underside of branches /large leaves, exposed buttress roots and large cracks within huge stems (Torr et al, 1999). Thus, conditions for tsetse survival in the Lake Victoria basin are generally suitable in terms of temperature.

1.12.3.3 Humidity

Relative humidity (RH) is a measure of the amount of moisture (water vapour) in the air relative to the total amount of moisture the air can hold. Humidity levels in the atmosphere will determine the presence of clouds and resultant rainfall. Therefore, one major purpose for measuring RH is to determine the prospects of rainfall for a given region. RH is measured in percentages (i.e. percentage of the total amount of water vapour that could be in a given amount of air). Long term humidity levels for the Lake Victoria basin can be computed from climatic data from selected weather stations in the basin or simply can be obtained as surrogate from remote sensed data. Humidity levels in a given area do influence the status of tsetse flies activity and availability (Bursell, 1957).

1.12.3.4 Vegetation cover

The region under study has a variation in vegetation ranging from low altitude vegetation through plateau vegetation to highland vegetation. Vegetation variation is due to differences in temperatures, rainfall, surface drainage, altitude and human activity among other factors, experienced within the different parts of the study region. Based on a preferred land cover classification system, one can have as many as 20 or more different vegetation classes for the region. The list of Landcover classes present within the Lake Victoria basin is adopted from the landcov2009 dataset and will be discussed further as an essential component of the key model covariates. Fine spatial resolution vegetation data to a significant extent offers average representation of other environmental conditions prevailing in a geographical setting like; average surface and air temperature, humidity, rainfall and relative altitude. Cecchi et al (2008), argue that "land cover directly or indirectly relates to all the main factors in tsetse ecology, such as global and local climate, vegetation cover and availability of wild or domestic feeding hosts". They further assert that all environmental variables can be assumed to be strongly correlated with vegetation cover. Landcover can therefore be used as a proxy for indicating tsetse presence / absence in an area.

1.12.3.5 Surface water

Surface water is a term used to refer to all water holding features on the Earth's surface. Such features include; rivers / streams, lakes, swamps, oceans, canals etc. The region under study is well endowed with abundant surface water which is fairly distributed across the entire region. Lake Victoria is the major surface water feature in the region and most of the other water networks are directly or indirectly linked to it. There are numerous rivers and streams spread across the region, most of which drain into Lake Victoria and in limited cases into Lake Kyoga. The pattern of surface water distribution is of great significance in determining the presence and abundance of tsetse flies in a given area. Thus, understanding the drainage pattern for an area can improve the plans for targeted tsetse control interventions.

1.13 Research concept

The precise distribution and abundance status of tsetse flies in Uganda is not clearly known, limiting the information with which to guide vector and disease control interventions (Tsetse situation report; Tsetse control division, MAAIF 2010). Therefore, the core objective of the study was to explore and make use of existing spatial statistical tools to generate reliable tsetse vector distribution maps at sub-national level. It is envisaged that with suitable input data, well selected model parameters and suitable analytical procedures, high predictive precision outputs will be obtained. Thus, the key outputs will be (i) a reliable sub-national tsetse risk map of the study area in Uganda, (ii) tsetse presence / absence maps for *G. f. fuscipes* (iii) tsetse abundance maps, and (iv) enhanced understanding of the association between environmental variables and tsetse distribution in Uganda. These outputs are expected to feed into the spatial analysis model that can among other things be used to investigate and measure the spatial relationship between location-specific sleeping sickness cases / Nagana and vector presence. This, as a result contributes to the process of accurately guiding control interventions for community welfare improvement.

1.14 Research approach

This research study was based on contemporary spatial epidemiological models. An entomological survey was conducted as part of the study objectives. A sampling procedure involving the use of remote sensing (RS), Geographical information Systems (GIS) and Global Positioning technologies was designed and adopted for the study. Analysis and mapping of entomological field data was performed to provide an understanding of the apparent tsetse situation in the study area. The results were point-based, and thus there was a need to produce continuous surface maps through modelling. Five regressional models (spatial and none-spatial) were developed to predict the spatial variation in presence and abundance of *G. f. fuscipes* across the SE Uganda landscape based on satellite-sensor derived environmental and climatic surrogates in combination with the entomological field data. The models were to account for and provide estimated values for the unsampled positions, and thereby enabling the production of continuous surface tsetse maps.

Data on quantitative historical measurements for the tsetse vector and trypanosomiasis including past interventions, were obtained from districts, institutions, ministries and agencies in the form of published and unpublished materials (i.e. records, reports and bulletins). Interpersonal interactions in the form of formal interviews and unstructured discussions with tsetse and trypanosomiasis experts were carried out throughout the course of the study. This information so gathered was used to answer the study objectives.

1.15 Thesis structure

This Thesis is structured into seven chapters. **Chapter Two** is an evaluation of past tsetse and trypanosomiasis control efforts. **Chapter Three** describes the methodology applied during data collection as "An entomological survey of the Lake Victoria basin to assess tsetse distribution and apparent densities". **Chapter Four** describes the modelling approaches applied in answering the question of "*where are the tsetse flies*?" **Chapter Five** describes the modelling approaches applied in answering the question of "*how many flies are there*?" **Chapter Six** gives a discussion of all results, while **Chapter Seven** presents the conclusion and recommendations.

CHAPTER 2: A REVIEW OF PAST TSETSE AND TRYPANOSOMIASIS CONTROL EFFORTS IN UGANDA (1960-2010)

2.1 Introduction

Uganda is heavily infested with tsetse flies transmitting both human and animal trypanosomiasis. In humans, the disease is associated with high morbidity and mortality rates. In livestock, trypanosomiasis causes high economic losses due to reduced animal production and productivity, leading potentially to food insecurity and socio-economic under-development in disease endemic areas. The removal of animal trypanosomiasis from Uganda could generate direct economic benefits in the region of US$400 million in a period of only 20 years (Shaw et al. 2013).

Over the last 100 years efforts have been made to control tsetse flies using various methods that included; selective bush clearing, selective game elimination, preventing movement of game animals into certain areas, temporary evacuation of cattle and people from tsetse infested to tsetse free areas, burning of vegetation to reduce the tsetse fly habitat, establishment of tsetse pickets (to de-fly the pedestrians, cyclists and motorists) and establishment of human settlement schemes on land freed from tsetse infestation to prevent tsetse re-invasion (Kangwagye and Latigo 1991). These methods made a contribution towards the achievement of "tsetse eradication" effectively leading to population protection in some parts of Uganda (Kangwagye 1987). However, such achievements were short-lived due to lack of sustainability. Furthermore, the interventions were localized and could not address the problem on an area-wide basis. Otherwise, the eradication of tsetse flies can remove constraints to both human and animal health leading to better livelihoods and overall rural development. Recent advances in technology have demonstrated that tsetse flies can be eradicated and trypanosomiasis eliminated (Kgori et al. 2006; FAO 1982; Vreysen et al 2014).

In this study, the achievements are evaluated for the various tsetse control programmes since 1960 to-date. An analysis of what was applied, what worked, what didn't, and why it didn’t as linked to the broader vector and disease control system is considered. The findings provide a platform for promotion and sustenance of demonstrably effective vector and disease control strategies.

The remainder of this chapter is structured as follows; study objectives, methodology, findings, discussion and conclusion.

2.2 Study objectives

The main objective of this chapter was to investigate and describe the variation in approaches and achievements regarding past and present tsetse and trypanosomiasis control interventions in Uganda. This was intended to provide a description of the historical enumeration of control events and an account of opinions about the tsetse and trypanosomiasis control strategies in Uganda.

The specific objectives for conducting this study were:

(a) To investigate the tsetse and trypanosomiasis control approaches used since 1960 and to quantify their levels of success.

(b) To establish the extent of Tsetse/HAT/AAT control investments for the *T.b.rhodesiense* focus (SE Uganda) over the past 50 years.

2.3 Methodology applied and protocol used in data collection

This study was undertaken to review and understand the various tsetse control strategies that have ever been applied within the past five decades in Uganda with specific focus on SE region. This as result is expected to inform researchers and policy makers about what has happened before and how it could be of benefit to planning for the future. The study involved collection of data using two main methods. These included mainly; (i) Interviews and (ii) records /document search. Details of the approach followed in data collection are contained in the data collection protocol provided in the appendix 1. Interview method as an important source of primary data, was used to gather information concerning expert opinion and experience on tsetse and trypanosomiasis programmes implementation over the past 50 years in Uganda. Whilst, records and document search method was used to obtain secondary quantitative data from both published and un-published types of material.

Data collection design and process

The study will involve collection of data using two main methods, (i) Interviewing and (ii) records /document search. Data will be collected by the researcher himself but will occasionally be supported by two research assistants to cover especially distant respondents within Uganda and overall to mobilize and sort records. Where Assistants will be engaged in interviewing, forms and templates of structured questions will be given to them to ensure that the actual targeted information is collected.

Records search and review method

This will be the main source of secondary data. The expected sources of such data will be;

A. Published reports

- By COCTU, MAAIF and Ministry of Health (MoH)
- By local Governments
- By Uganda Bureau of statistics in form of Statistical abstracts, census reports and other reports.
- Journals, magazines and periodicals.
- Works of research institutions and Universities etc.

B. Un-Published reports

- Records and statistics maintained by various departments / projects at districts and headquarters (MAAIF, MoH & COCTU). Eg project reports, quarterly reports, conference papers, and ministerial reports.
- The research works carried out by scholars / researchers / professionals.

Interview method

Interviews will be of a Focused /semi-structured type and will be aimed at tapping particular experience, motivation and opinion of selected informants. This will be the main source of primary data. Expected informants for proposed interviews are;

- Senior serving government officers in MAAIF and Ministry of Health (MoH)
- Long-serving district staff .i.e entomologists, health officers, veterinary officers and vector control officers
- Tsetse and trypanosomiasis experts from LSTM, LSHTM, UoE, FAO, WHO, IAEA, AU-PATTEC & AU-IBAR
- Retired senior tsetse and trypanosomiasis personnel
- Coordinator – National Sleeping Sickness Control Programme of Ministry of Health (MoH)
- Tsetse and trypanosomiasis Project Coordinators
- Research institutions like Makerere and NaLIRRI (formerly East African Trypanosomiasis Research Organization -EATRO)
- Commercial Livestock farmers from selected regions.

Data accuracy

All data gathered especially secondary data, will be scrutinized for its reliability, suitability and adequacy using data exploratory methods.

2.3.3 Data analysis:

Data collected by the various methods was analysed quantitatively and qualitatively to extract issues that emerged. Specifically, quantitative analysis focused on data for cost of control operations.

2.4 Findings

Results from this study are presented chronologically following specific intervals of years (i.e. 1900–1970, 1971–1980, 1981–1990, 1991–2000 and 2001–2013). For each period an analytical review of the tsetse and trypanosomiasis control operations and programmes is made.

2.4.1 Period 1960-1970

During the period (1900-1970), tsetse infestation was known to cover close to 40% of the entire country and was distributed across two belts (Figures: 4; 5; 6; 7). The first tsetse belt of about 47,000 km^2 stretched from south of Lake Edward in South western Uganda northwards to include the entire Uganda-Sudan border and had a total of seven Glossina species (MAAIF Tsetse Control Department- report, 1992). The second tsetse fly belt occupied an approximate area of 50,000 km^2. This belt stretched from the shores of Lake Victoria on the Uganda-Tanzania border through Lake Kyoga basin up to the Uganda-Sudan border in the northern and north-eastern regions of the country. The presence of *T.b.rhodesience* sleeping sickness in S.E Uganda and *T.b.Gambiense* sleeping sickness in N.W Uganda is spatially linked to these two tsetse fly belts. During that period, AAT was considered a common phenomenon in the cattle population within the low, medium and high tsetse fly challenge areas of the country. During that period, close to 70% of the national herd was considered as being exposed to the AAT risk (Veterinary services report-MAAIF, 1989).

Therefore, the strategy to eradicate tsetse during the period 1900-1970 was driven by the imminent threat of tsetse flies to livestock production and productivity. There was a critical need to free potential areas from tsetse flies to enable livestock-keeping to take place. Consequently, in 1947 the Tsetse Control Department of the Ministry of Animal Industry and Fisheries was formed to halt tsetse advances into livestock producing districts and to reclaim infested land for increased livestock production, crop cultivation and human settlement (Kangwagye et al. 1987; COCTU report 1990). At that time, the methods in use even in other countries included; bush clearing (total and selective), game elimination through hunting, game eviction, cattle evacuation, maintenance of tsetse pickets, application of insecticide on cattle, and ground spraying using insecticide (Dieldrin-3%). These interventions were geared towards either removal of the tsetse habitat or direct killing of the tsetse flies.

As strategic action, government with support of external partners identified potential livestock keeping zones for protection against tsetse flies. Selected zones were spread across the country but mostly covering western and northern parts of Uganda. The zones were demarcated into blocks (tsetse schemes) which were treated by ground insecticide spraying using Dieldrin-3%. Ground insecticide spraying is a labour-intensive procedure where the insecticide is applied either directly to distinct parts of the vegetation, e.g. tree-trunks up to a certain height (tsetse resting range), underside of inclined branches etc all by means of pressurised spraying equipment, for the purpose of killing tsetse flies. Other chemicals used in ground spraying against tsetse flies, though to a limited extent at the time, were DDT and Endosulfan. Table: 3 and Figure: 12 show the different tsetse schemes which benefited from ground spraying during the period 1961-1970.

Table 3 Tsetse reclaimed areas by ground spraying using 3% Dieldrin E.C (1961–1970)

	Tsetse Scheme	Tsetse Area Reclamation (km^2) 1961-1966	Tsetse Area Reclamation (km^2) 1966-1970	Total area reclaimed (km^2)1961 – 1970
A	Ankole Tsetse scheme	1,669	3,400	5,069
B	Bunyoro / Lango tsetse scheme	1,900	1,500	3.400
C	North Karamoja (Kotido) tsetse scheme	650	--	650
D	Lake Nakivale / Ruhengere tsetse scheme	230	--	230
E	Acholi / Karamoja scheme	--	700	700
F	Toro scheme	--	300	300
G	Aswa valley scheme	--	1,100	1,100
	Total	**4,449**	**7,000**	**11,449**
	Note: 1. 4400 km^2 of land was reclaimed from tsetse through game elimination (hunting) in Ibanda and Kazo counties within Ankole region alone – (1958-1962). 2. Manual bush clearing was conducted in Ibanda (Mitooma) county – (1955-1960) 3. Mechanical bush clearing was conducted in Buganza and Kahisimbi – 1962-1967 4. Insecticide spraying using Dieldrin done in Nyabushozi county – 1963-1964 5. Insecticide spraying using Dieldrin done in Lake Mburo area – 1965-1968 **6.** Insecticide spraying using Dieldrin done in Bukanga and Isingiro counties – 1968-1969			

Source: COCTU report (1987)

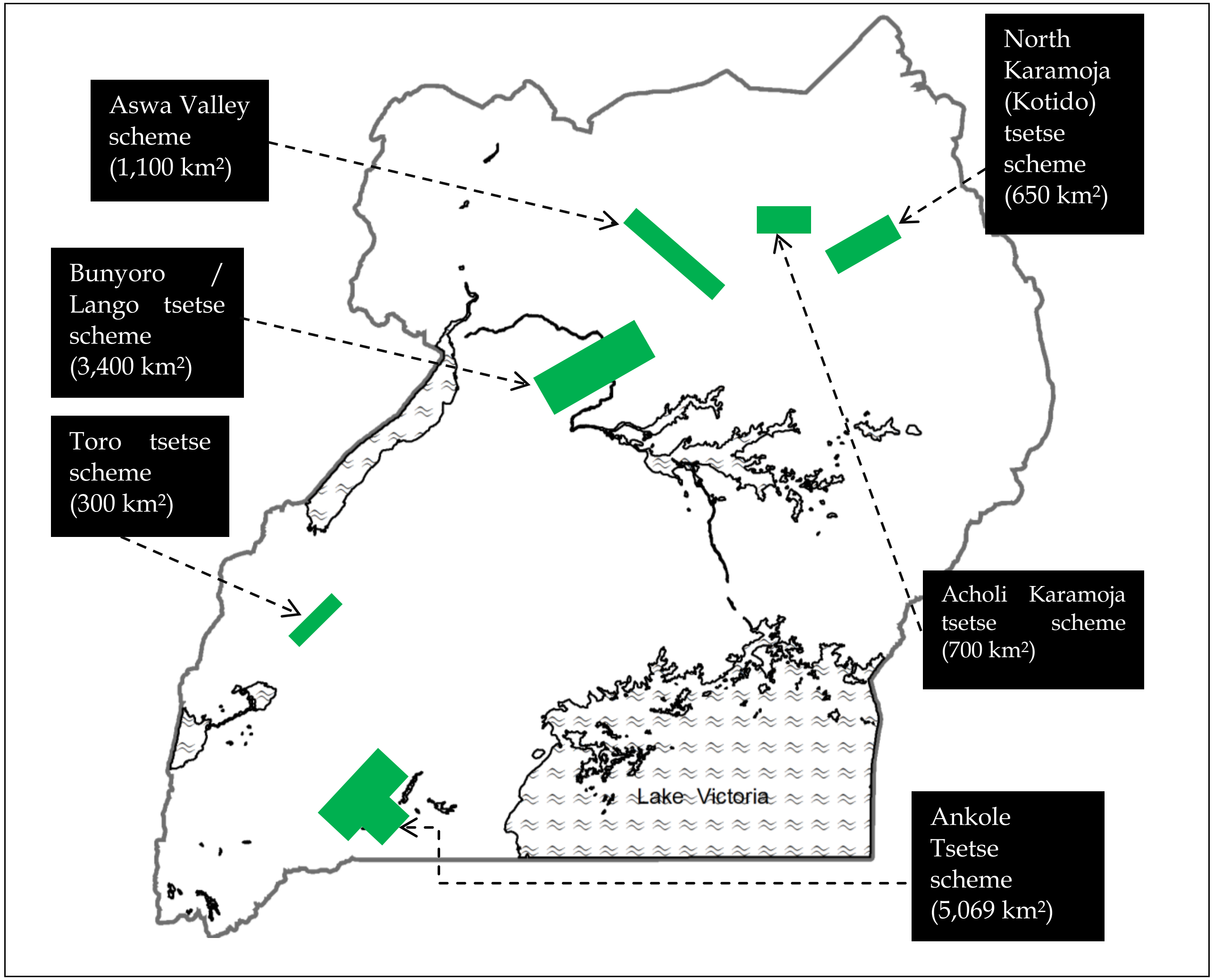


Figure 12: Tsetse eradication - Ground spraying zones (1961 – 1970)

Source: Map constructed using information from COCTU reports of 1987

A total area of 11,449 km^2 of land was reclaimed and made available for both commercial and subsistence animal farming including settlement (COCTU report 1987). The famous Ankole-Masaka ranching scheme and many others, were established on the tsetse reclaimed land. Tsetse control operations were centrally funded and managed by government and carried out through ground spray units with over 500 contracted workers per unit. The community had no direct role in the operations. At the time, bush clearing was the method applied in creation of tsetse barrier zones. Maintenance of barrier zones was a key challenge in realising the full benefits from tsetse eradication. While these interventions had significant impact on creation of tsetse free zones at the time, the approaches especially those involving bush clearance and game elimination, greatly contributed to environmental degradation.

For most of the early 1900s disease management in both humans and livestock was controlled through treatment of animals and people with clinical symptoms of trypanosomiasis. In some instances there was evacuation of population at risk of disease contraction. To break the transmission cycle, humans had to be shifted from areas of high tsetse infestation to areas of low or no infestation.

2.4.2 Period 1971-1980

This period witnessed an extension of activities which had been initiated during the previous decade (1961–1970). Specific zones were selected from Busoga, Bukedi, Toro, Acholi, Lango, Bunyoro and West Nile provinces (Figure: 13). During the intervention, an estimated ground area of 5073 km^2 (Table: 4) was freed from tsetse flies using ground spraying with Dieldrin insecticide (COCTU annual report 1990). Like in the previous decade, the reclaimed land was put to both commercial and subsistence farming.

Table 4 Tsetse eradication activities (Ground spraying) during 1971 - 1980

Year	Busoga / Bukedi (km²)	Toro / Mubende (km²)	Acholi / Lango (km²)	Bunyoro / Bulemezi (km²)	West Nile / Madi (km²)	Total Area (km²)
1971	117.16	-	131.84	120.69	-	369.69
1972	251.76	422.82	-	415.05	-	1,089.63
1973	106.99	222.58	359.63	106.93	-	796.13
1974	132.31	283.98	171.9	145.43	195.04	928.66
1975	43.62	115.11	35.25	42.23	339.84	576.05
1976	9.70	38.10	109.78	41.86	105.07	304.51
1977	52.29	73.31	39.82	104.52	123.6	393.53
1978	41.55	33.64	75.10	102.53	64.89	317.71
1979	250.35	15.00	2.16	30..6	-	297.57
TOTAL	1,005.73	1,204.54	925.48	1,079.24	828.44	5,073.48

Source: Tsetse control department-MAAIF-1980 in COCTU report of 1990

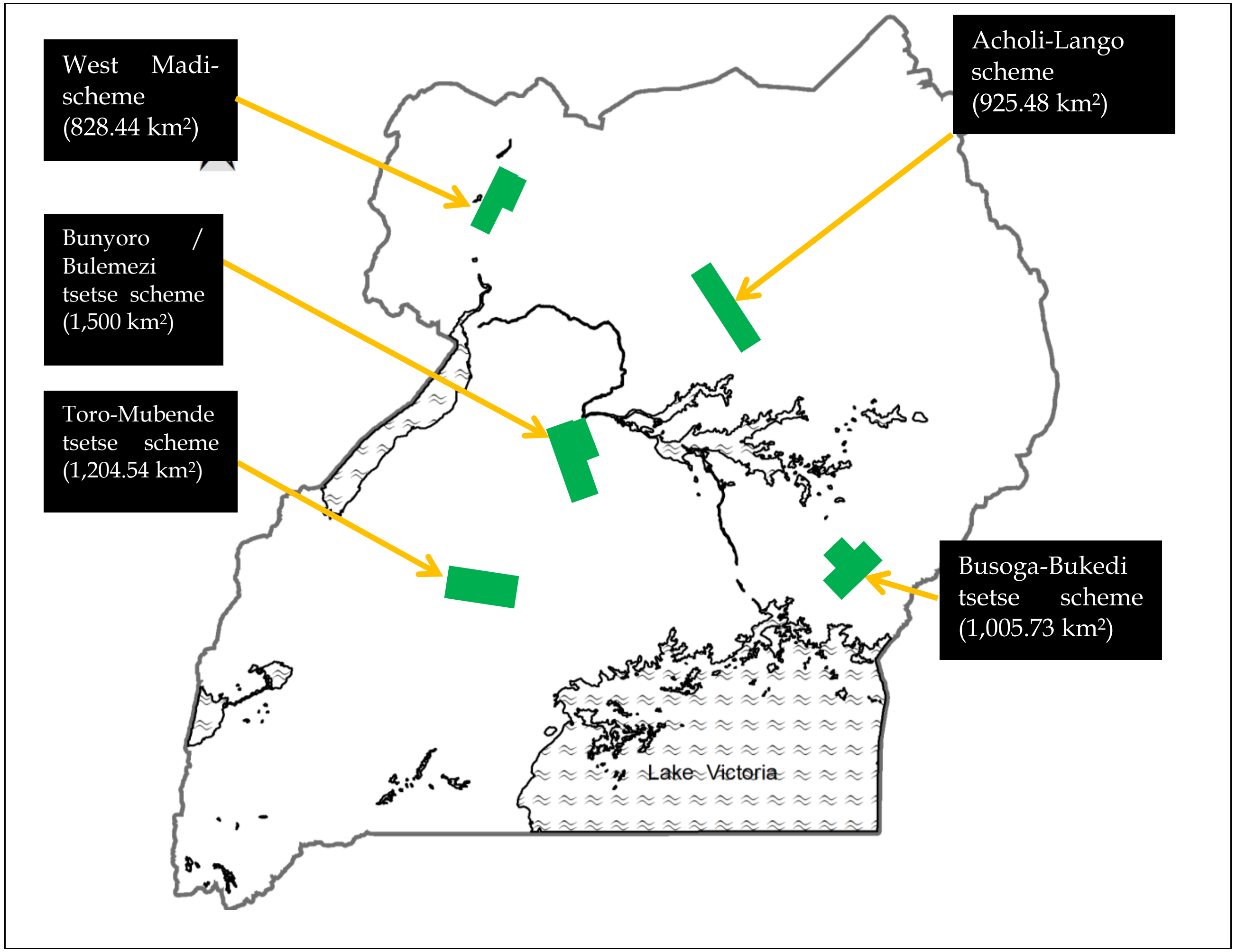


Figure 13: Tsetse eradication - Ground spraying zones (1971 – 1980)

Source: Map constructed using information from COCTU report of 1990

The impact of the interventions was evaluated using evidences of residual tsetse flies in the reclaimed area, reduced AAT prevalence, increased livestock in the area coupled with increased human settlement. However, in an attempt to consolidate achievements, measures were introduced in the tsetse reclaimed zones (Kangwagye, 1991). Such measures included;

- Use of insecticide sprayed cattle as live baits to kill residual tsetse flies
- Encouragement of late burning of grasses to temporarily reduce the tsetse habitat.
- Establishment of pickets at strategic movement sites to defly the pedestrians, motorists and cyclists.
- Livestock evacuation; where especially cattle were removed temporarily from certain areas to allow meaningful re-treatment of some areas.
- Establishment of human settlements to make use of reclaimed lands.

2.4.3 Period 1980-1990

The period (1980-1990) witnessed a lot of successful tsetse control operations. During this period approximately 97% of the country’s tsetse eradication activities were concentrated in the Busoga region where over 6000km^2 of land was reclaimed from tsetse infestation (Table: 5). These activities were all triggered by the then alarming HAT cases that were being registered in mainly the South East region of Uganda (Mbulamberi 1989, Berrang-Ford 2007). The target was to halt the HAT outbreak using quick and efficient methods like aerial spraying (Sequential Aerial Technique, SAT).

To maximise impact, the programme implementers applied integrated tsetse control strategies all aimed at addressing two main problems, namely;

(i) The increasing sleeping sickness prevalence and incidence in SE Uganda and,

(ii) The high tsetse fly infestation in many parts of SE Uganda.

Due to persistent outbreaks of sleeping sickness in the region, a team of experts suggested and recommended the adoption of an integrated use of; ground spraying, selective bush clearing, use of impregnated traps/targets and aerial spraying where possible (COCTU report 1992). This was considered as the best response intervention to the sleeping sickness epidemics. This expert advice was experimented on the 1987 outbreak in which over 6,500 cases had been recorded within the SE region of Uganda.

During that time, it was considered that the best approach to tsetse and trypanosomiasis control in Uganda was by two fronts i.e. the short-term approach (emergency) and the long-term approach. Each of these fronts would have an integrated programme encompassing disease surveillance, vector control and some aspects of land use planning. The emergency front would be a plan of strategies aimed at immediately breaking the disease transmission cycle for *T.b.rhodesiense* in the south eastern focus.

The long-term front was expected to consolidate achievements from the emergency phase but also establish strategies for total tsetse fly eradication and sleeping sickness elimination from the region in particular and the country in general.

Table 5 Tsetse eradication activities undertaken during 1980 - 1990

Year	Busoga (Km^2)	Toro/ Mubende (Km^2)	Acholi/ Lango (Km^2)	Bunyoro/ Bulemezi (Km^2)	West Nile / Madi (Km^2)	Total Area (Km^2)
1980	2157**	30.26	-	10.11	-	2197.37
1981	105.40	11.21	0.98	-	-	117.59
1982	1380**	-	-	-	-	1380
1988	1525**	160	-	-	-	1,685
1990	1,100**	-	-	-	-	1,100
TOTAL	6,267.40	201.47	0.98	10.11	-	6,479.96
*** Aerial spraying using either Deltamethrin or Dieldrin 20% ULV*						

Source: Annual reports: MAAIF Tsetse control department- -1990

A significant part of this period witnessed civil strife in initially central Uganda but later in northern and north-eastern Uganda. These wars halted field tsetse control activities in districts of Luwero / Mubende, Gulu, Kitgum, Kotido and Apac districts. Under similar circumstances, tsetse control campaigns under the IFAD/ADP programme in north eastern Uganda (Kumi and Soroti districts), were discontinued. Over time, this meant that previously reclaimed areas in northern Uganda (10,000 km^2), Kotido district (2,000 km^2) and Maruzi peninsula of Apac district (1,800 km^2) were re-infested by tsetse flies (COCTU report 1992). This period further faced a problem of resettlement of Sudanese refugees into the hinterland of Kiryandongo district with a danger of introducing gambiense sleeping sickness in the area, with a high possibility of expanding to Hoima, Luwero and Masindi districts (COCTU report 1992).

During this period (1980-1990), the following tsetse control methods were used;

a. Ground spraying with 3% Dieldrin emulsion
b. Aerial spraying using Endosulfan insecticide for suppression of tsetse population
c. Tsetse fly trapping with Deltamethrin impregnated pyramidal tsetse traps against *G. f. fuscipes* in South East and to a limited extent biconical odour baited traps and targets.
d. Pour-on application of Deltamethrin on livestock to act as live-bait.
e. Limited bush clearing especially of *lantana camara*, an ideal habitat for *G. f. fuscipes* in SE Uganda.

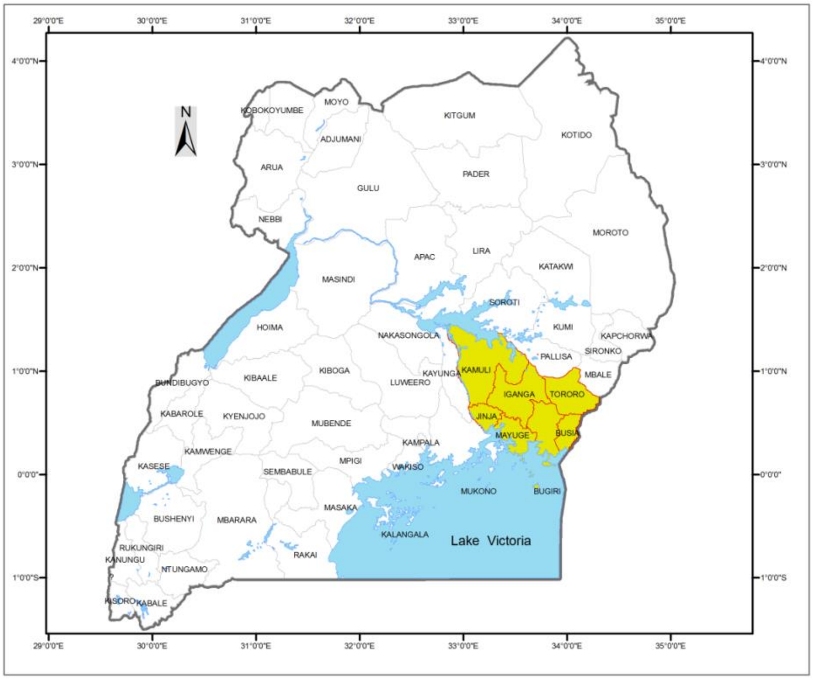


Figure 14: Tsetse trapping zones in SE Uganda during the period 1980 - 1990

Ground Spraying: In SE Uganda, ground spraying was applied to specifically create a tsetse barrier zone to protect SAT treated areas from possible tsetse fly re-invasion. As a result, a barrier of approximately 300 km^2 was created for that purpose. Overall the use of ground spraying in SE Uganda was quite limited.

Aerial Spraying: Aerial spraying, also referred to as Sequential Aerosol Technique (SAT) is the application of insecticides on target vectors by spraying using low flying aircraft. First aerial spraying against tsetse flies was conducted in Busoga and Bukedi regions in 1980 (2157 km^2) followed by another spraying in 1982 covering 1380 km^2 (Kangwagye and Latigo 1991). Subsequently, spraying with five sequential application of Endosulfan against *G. f. fuscipes* was endorsed and undertaken with the assistance of the

Desert Locust Control Organisation for Eastern Africa (DLCO-EA) in areas previously covered in 1980 (COCTU report 1992).

Phase I of 600 km^2 and **Phase II** of 925 km^2 were covered between January – March 1988 and June –August 1988, respectively. This was mainly to halt the HAT epidemic in the counties of Kagoma and Butembe (Jinja district), Buzaya / Bugabula (Kamuli district) and Luuka/Kigulu (Iganga district). Endosulfan was uniformly sprayed over tsetse habitats by a DLCO-EA fixed wing aircraft. The tsetse apparent density reduction percentage achieved as a result was between 76.6% and 100% over the two phases. Cases of sleeping sickness decreased in the treated areas by over 50% (COCTU report 1992). Table: 6 shows the annual HAT cases from intervention counties during the period 1984 to 1992. Aerial spraying was conducted in 1988 specifically covering two counties i.e Kagoma and Butembe, both located within Jinja district.

Table 6 HAT cases by County in SE Uganda (phases 1& 11 done in 1988)

County	**HAT Cases**								
	1984	**1985**	**1986**	**1987**	**1988**	**1989**	**1990**	**1991**	**1992**
Kagoma	286	281	664	1102	257	38	7	15	5
Butembe	47	50	63	208	99	22	8	8	5
Luuka	344	450	480	751	265	75	20	20	16
Buzaaya	85	152	357	577	180	44	17	13	21
Bugabula	31	104	198	377	250	162	47	15	62
Kigulu	548	926	764	758	345	67	18	33	62
Bunya	158	179	319	845	263	142	59	55	51
Bugweri	56	124	149	186	139	52	17	3	9
Bukooli	102	180	259	601	413	146	81	42	41
Source: COCTU sleeping sickness report 1994									

It is highly believed that this intervention by aerial spraying which caused a gross reduction in tsetse apparent densities of close to 90% within treated areas, was responsible for the over 50% reduction in HAT incidence (Figure: 10). Figure: 15, shows the sharp trend in reduction of HAT cases to almost zero following the tsetse control by aerial spraying in the two counties of Butembe and Kagoma (Busoga). We observe that cases which had reached a level of 1,102 in Kagoma county alone in 1987 were reduced to only five by 1992 (Figure: 15).

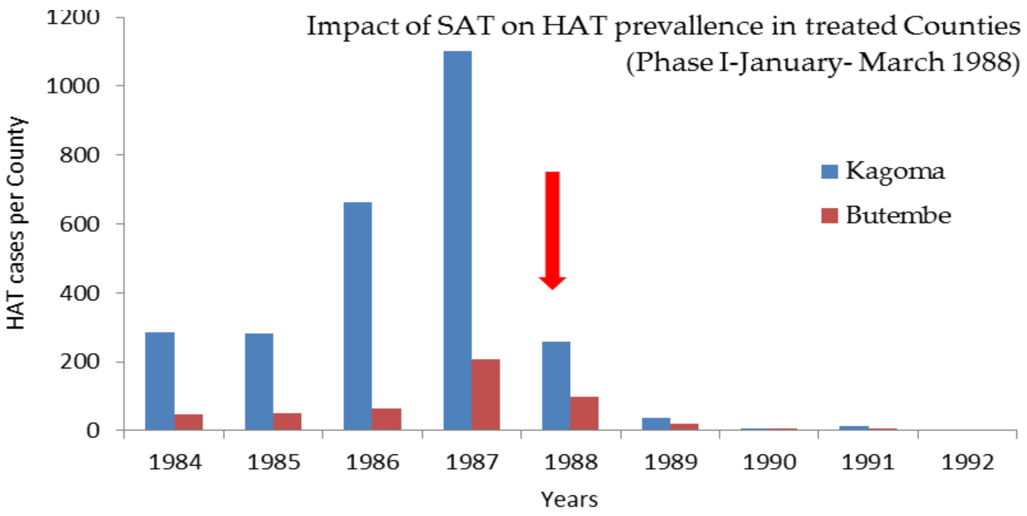


Figure 15: HAT prevalence in Kagoma and Butembe counties (SE Uganda)

Figure: 16, shows the presumed impact of aerial spraying in the counties of Luuka, Buzaya and Bugabula on HAT cases during the period 1984 – 1992. The graph clearly shows a sharp decline in the number of cases after the SAT intervention in mid-1988. Cases which were as high as 751 in Luuka County alone in 1987 were reduced to only 16 cases by 1992.

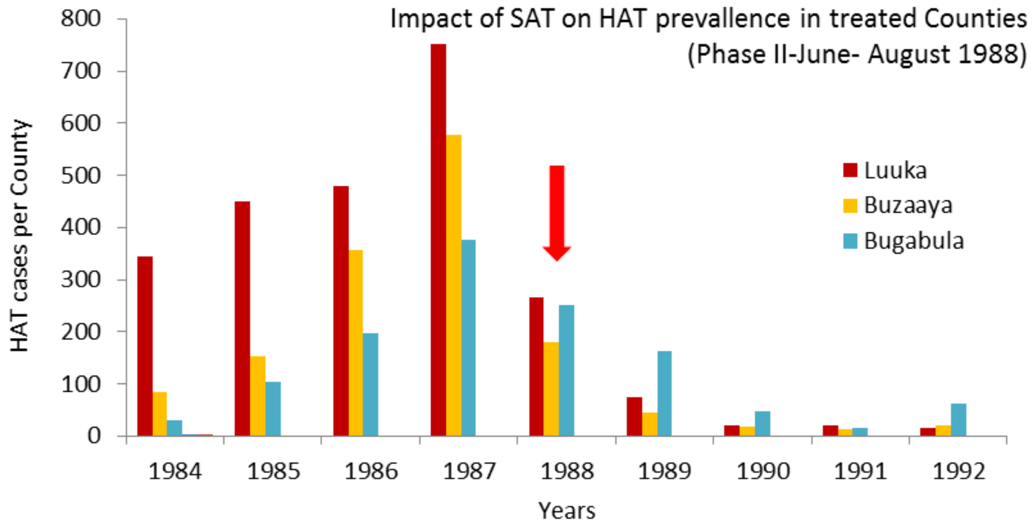


Figure 16: Trend of HAT prevalence in counties of Luuka, Buzaya and Bugabula (1984-92)

Phase III of aerial spraying in SE Uganda was conducted between January and April of 1990 in the counties of Bunya (Mayuge district), Bugweri, Kigulu and Bukooli (Iganga district). Demarcation of spray blocks was done using major existing roads e.g. the Bulanga-Idudi-Busembatia road acted as a spray boundary to the north while the Bulanga-Mayuge-Nankoma-Irimbi road was used as a boundary limit to the south (map of actual spray blocks in appendix 11). This enclosure provided a spray block of 1,100 km^2 of ground area. The four counties were targeted essentially because of the expanding sleeping sickness crisis involving a computed average of 1370 cases per year between 1985 and 1989 from the four counties (Kangwagye et al. 1991, Lancien et al. 1990).

During the third phase of SAT application carried out in 1990, a total of 39,475 litres of Endosulfan chemical was used in 193 spray flying hours. Aviation fuel used was 26,000 litres (Kangwagye et al. 1991). An average dosage rate of 8.5 litres/km^2 was sprayed depositing an average 25.5 g / ha of active ingredient.

Table 7, HAT prevalence in the counties of Kigulu, Bunya, Bugweri & Bukooli (1987 – 1992) - SAT Phase 111 was done in 1990

	HAT Cases								
County	**1984**	**1985**	**1986**	**1987**	**1988**	**1989**	**1990**	**1991**	**1992**
Kigulu	548	926	764	758	345	67	18	33	62
Bunya	158	179	319	845	263	142	59	55	51
Bugweri	56	124	149	186	139	52	17	3	9
Bukooli	102	180	259	601	413	146	81	42	41
Total	**864**	**1409**	**1491**	**2390**	**1160**	**407**	**175**	**133**	**163**
Source: COCTU sleeping sickness report 1994									

The impact of the aerial spraying was measured using pyramidal traps uniformly distributed across the sprayed block. Reduction in *G. f. fuscipes* apparent density varied between 99.3% to 100% (Kangwagye et al. 1991). The number of sleeping sickness cases from the four counties was reduced from 407 in 1989 to 175 cases by the end of 1990, representing 60% reduction. Figure: 17 presents the sharp downward trend of HAT cases soon after aerial spraying intervention.

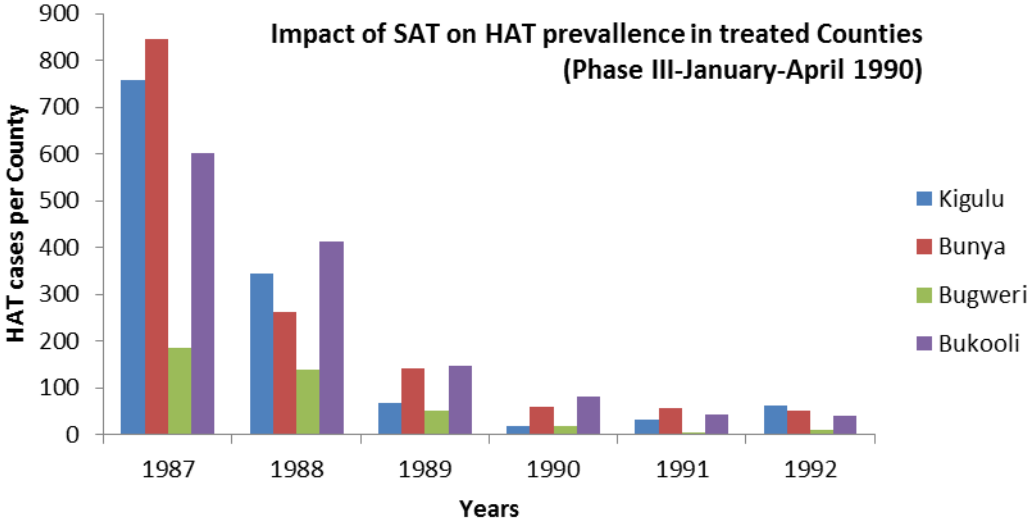


Figure 17: HAT prevalence in the counties of Kigulu, Bunya, Bugweri & Bukooli (1987 – 1992)

a. Use of pyramidal traps against tsetse flies in SE Uganda

In 1987, the European Economic Community (EEC) gave Uganda a grant of ECU 2.4 million to implement multi-disciplinary field activities on tsetse and trypanosomiasis. The activities covered the three components i.e. entomology, veterinary and medical. Field activities included; tsetse trapping using pyramidal traps, screening for HAT, mass treatment of cattle, spraying of animals and intensified disease surveillance. Use of pyramidal traps originally designed in Central Africa by two French workers Janick Lancien and Gouteux in 1985 were introduced in Uganda in 1987. These traps are most suitable for trapping *G. f. fuscipes* (Gouteux et al. 1995; Vale et al. 1979; FAO, 1982). Each pyramidal trap was impregnated with Deltamethrin insecticide. These traps were deployed in the field at an average spacing density of 8 traps per km^2. This resulted in a decrease in tsetse population by 90% in an area of 3,300 km^2, reduction in numbers of sleeping sickness cases from 9,000 to less than 1,000 per year and prevalence of animal trypanosomiasis from over 40% to 8% (Mbulamberi 1989; Kangwagye et al. 1991)

In order to break the transmission cycle of *T.b.rhodesiense* in SE Uganda, tsetse fly trapping using pyramidal traps was intensified in 1989. Over 30,000 pyramidal traps were deployed in the high risk Subcounties within Kamuli, Iganga and Tororo districts (Table: 8). The pyramidal trap was preferred because of the following advantages; (i) It was cheap ($3), (ii) It was considered sensitive for both survey and control, (iii) Could be used with or without impregnation, (iv) It had the ability to retain the fly catches without additional devices and (v) It was easy to set-up in the field and easily adopted by the community (Lancien et al. 1990).

Table 8 Cumulative deployment of pyramidal traps in SE Uganda (1987-1991)

	District / Subcounty	No. of traps	No. of tsetse flies caught
A	Kamuli district		
1	Namugongo	1,250	309
2	Bumanya	1,160	198
3	Kitayundwa	2,960	797
4	Namwendwa	2,980	3,351
B	Iganga district		
5	Nsinze	1,260	916
6	Magada	2,280	2,474
7	Ivukula	2,160	335
8	Namalemba	2,300	1,485
9	Nawandala	550	27
10	Namwiwa	1,040	4,502
11	Kibaale	960	407
12	Bukova	4,180	4,691
13	Ikumbya	2,360	483
C	Tororo district		
14	Iyolwa	4,020	4,702
15	Rubongi	1,600	13,201
16	Buteba	955	5,086
17	Busitema	160	403
18	Lumino	250	356
	TOTAL	32,425	43,723

Source: *Tsetse control department report 1992*

To support the intervention, two pyramidal trap manufacturing workshops were established in 1988, one in Bugiri district and another at Namugongo (Kamuli district). These were fully equipped using project funds. Trap manufacturers were identified among communities and trained to do the job. Figure: 18 is a photograph of one of the established community based trap manufacturing units while Figure: 19 is a pyramidal trap deployed in the field.

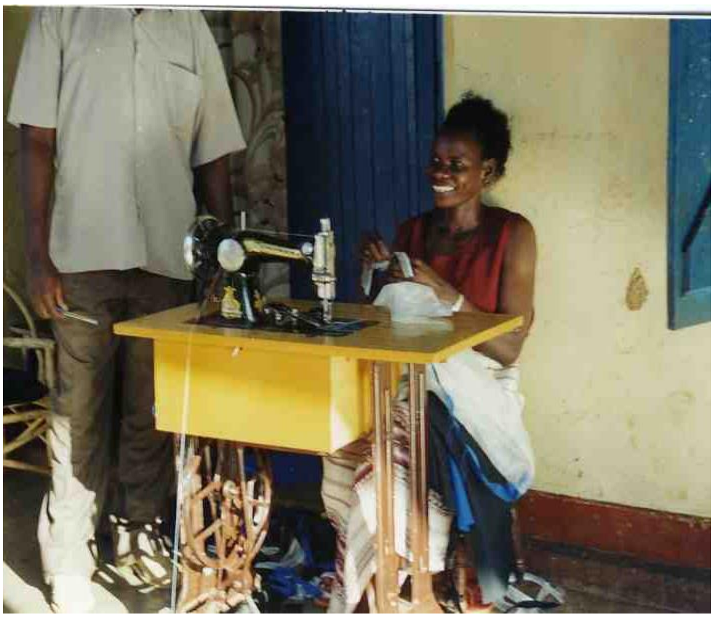


Figure 18: Trap manufacturing unit

Figure 19: A pyramidal trap in the field

The success of the intervention was linked to the well-shared responsibility of the programme activities between government and the local community as beneficiaries. Precisely, government through its technical team was responsible for supplying the required inputs (e.g materials and chemicals) including training of communities. On the other hand, communities were responsible for mobilisation, trap deployment and trap maintenance. Community participation was enhanced through formation of trypanosomiasis committees at various levels (i.e district, sub-county and parish levels). In total, there were 234 committees in 39 sub-counties by 1990 (COCTU report 1992).

Further, during the period 1980-1990, the Overseas Development Administration (ODA) of UK funded sleeping sickness activities specifically in Busoga region through the NSSCP. This was done in three phases i.e phase- 1(1985-1986), phase-2(1986/1987 – 1988/1989) and phase-3 (1989/1990 – 1991/1992).

Phase-I (1985/1986): This first phase had both short-term and long-term objectives. The short-term objectives included;

- To improve diagnosis at sleeping sickness treatment centres
- Improve and standardise management of sleeping sickness cases
- To activate active surveillance
- To develop an effective data collection, analysis and reporting system for the NSSCP
- To develop training programmes for health workers in clinical and epidemiological aspects of sleeping sickness.

The long-term objectives included;

- To define the extent and intensity of the epidemic and determine factors of importance in human transmission leading to a framework for the development of effective control strategies
- To attract further international funding especially in support of long-term programmes of effective vector control and reduced man-fly contact.

All the above objectives were to be achieved through provision of funding for revitalising active surveillance, laboratory equipment and technical assistance.

Phase-II (1986/1987 – 1988/1989): This phase was largely a capacity building phase, costed at £280,500. Through this phase, the necessary tools were provided. These included; laboratory equipment, bicycles, vehicles, computers and training of staff. The key objectives for the phase included;

- To equip at least 9 Sleeping Sickness Treatment Centres (SSTCs) and upgrade diagnosis and management of cases.
- To develop a system for active surveillance using field officers aiming at identifying 50-60% of all cases and using this system for follow-up patients after treatment.
- To establish a computer based data management and processing system.

Phase-III (1989/1990 – 1991/1992): This phase was costed at £415,000 and involved the following activities; consultancy visits by technical teams from Liverpool School of Tropical Medicine-LSTM, supervision of surveillance programmes, conducting trainings and upgrading /equipping of Namungalwe SSTC.

Thus, during the period 1980-1990 a total of 20 health centres were established within the SE focus and equipped for handling *T.b.rhodesiense*. Each health centre received laboratory / hospital equipment, drugs, office equipment and supplies including vehicles. The diagnosis of patients was based mainly on examination of slides by laboratory assistants while the cases were treated by medical assistants at the Sleeping Sickness Treatment Centres (SSTCs). Field interventions were determined by the number of human cases diagnosed monthly at sub-county. All medical results were recorded in a network of 20 SSTCs evenly distributed in the area. These medical results were collected at the end of the month and analysed at the project management office in Jinja. Such data provided the basis for decisions in determining control activities in the ensuing months.

Monitoring of progress under the medical component was based on the a detailed medical protocol of work for sleeping sickness emergency control programme of Ministry of Health**.** According to this protocol, the following parameters were used to monitor medical progress; (i)Number of persons examined, (ii) Percentage of sleeping sickness cases whose cerebro-spinal fluid (CSF) had been examined before treatment, (iii) Number of patients on record at the treatment centres with all the temperature and treatment charts complete and (iv) Number of Subcounties for which morbidity and mortality rates can be determined on the basis of the number of persons at risk, prevalence and mortality due to sleeping sickness observed during hospitalisation.

Prior to all the above efforts, an epidemic wave of sleeping sickness had been recorded in Busoga region affecting mainly Jinja, Kamuli and Iganga districts (Mbulamberi 1989; Kangwagye et al 1991). The epidemic was located within a belt of 40 km from the Lake Victoria shores and covered approximately 46,000 km^2. In these areas a rapid decrease of the number of sleeping sickness cases as a result of targeting interventions was observed between 1987 and 1992 from 6674 to 276, giving a reduction of 95.9% (Mbulamberi, 1989).

From 1988, the disease outbreak extended to Tororo and Mukono districts. After intervention of an integrated vector and AAT control, a similar decline in the number of sleeping sickness cases was observed in the two districts. However, in the lake shore area of Iganga district, the endemic situation which had prevailed since 1987 remained constant with only a small epidemic upsurge in Subcounties of Nabukalu (55 cases in 1994), Malongo (28 cases in 1992) and Kityerera (37 cases in 1989).

During the period under consideration (1980-1990), the main objectives for the veterinary component was to undertake activities that would limit disease transmission within Man-Animal-Tsetse fly. Such activities included; treatment of livestock, improvement of animal health and conducting adoptive research. However, in HAT endemic areas, veterinary interventions involved mainly the application of insecticides on domestic animals and block treatment of cattle with diminazine. This was in addition to tsetse vector control by trapping. Application of pour-on insecticide on livestock was done by farmers supported by the community workers. Block treatment of cattle with diminazine aceturate at no farmer cost was implemented only in high risk areas of transmission since farmers/peasants could not afford the cost of the treatment of their animals. Monitoring of AAT prevalence was done by the Veterinary Services Department of the Ministry of Agriculture Animal Industry and fisheries (MAAIF). In addition, limited adoptive research was conducted to confirm the methodologies under promotion for wider use. For instance, in Tororo district, a strategy which combined Deltamethrin application with trapping was introduced in three sub-counties and the results were compared with those from an area where only trapping was undertaken. This approach gave more satisfactory results with an increased reduction of the vector density of 95% in 3 months and a significant reduction of human cases. Tsetse trapping alone gave a reduction of up to 71% during the same period. Similar comparative results were obtained in Mukono district (Tsetse Control department report 1989).

2.4.5 Period 1990-2000

This period benefited from several tsetse and trypanosomiasis control projects. These were six in number and are as discussed below;

a. EEC Tsetse trapping programme in SE Uganda

During 1990-1991 and with funding from the European Economic community (EEC), French government and Government of Uganda (GOU) the tsetse trapping programme in SE Uganda continued to expand with commendable success. Progressive gradual decline of notified cases of human sleeping sickness had been achieved over a four year period (1987-1991) of tsetse trapping in SE Uganda (Lancien, 1991). The number of traps deployed increased from 2,800 in 1988 to 16,000 by end of 1993 (COCTU report 1992). During that period the area covered increased from 8 to 39 sub-counties totalling approximately an area of 5,850 km^2. A sustainable medical evaluation was implemented through a network of community health workers. Other activities responsible for success included; regular monitoring of tsetse fly densities, fly infection rates and the feeding behaviour of tsetse flies. To support disease and vector surveillance, a field laboratory was set up in Buikwe with financial support from EEC and Germany Technical Assistance (GTZ). The results obtained and lessons learnt through this programme testify that the approach was manageable, cost-effective, easily adaptable and sustainable.

b. Kenya-Uganda tsetse and trypanosomiasis control project - 1990

This cross-border project was supported by the Organisation of African Unity (now called African Union)/ Inter African Bureau for Animal Resources (OAU/ IBAR) with $44,974 to implement a tsetse and trypanosomiasis control project along the Kenya-Uganda border in the early 1990s. Out of this fund, NSSCP received $10,000 worth of equipment and medical supplies for implementation of an emergency sleeping sickness programme in the Kenya-Uganda border region. The medical approach was to screen most of the people living in the sleeping sickness foci along the border area and also treat all cases identified, while the entomological approach was to carry-out tsetse trapping using pyramidal tsetse traps. This resulted in screening of over 15,000 people from all affected sub-counties located along the border and tsetse apparent densities by 95%. In all this, health education about sleeping sickness and tsetse control was emphasized. This intervention was considered successful in rapidly controlling the sleeping sickness outbreak in the cross-border zone involving Kenya and Uganda.

c. Block Treatment in Kabarole District - 1991:

In 1991 the Overseas Development Administration (ODA) provided support worth £400,000 to the Veterinary Department of the Ministry of Animal Industry for block treatment of livestock against Nagana in Kyaka county within Kabarole district in western Uganda. Kyagegwa Sub-county in Kyaka County was chosen for the project of controlling trypanosomiasis infection in cattle. The process involved application of Samorin every three months for two years to all cattle in the Sub-county.

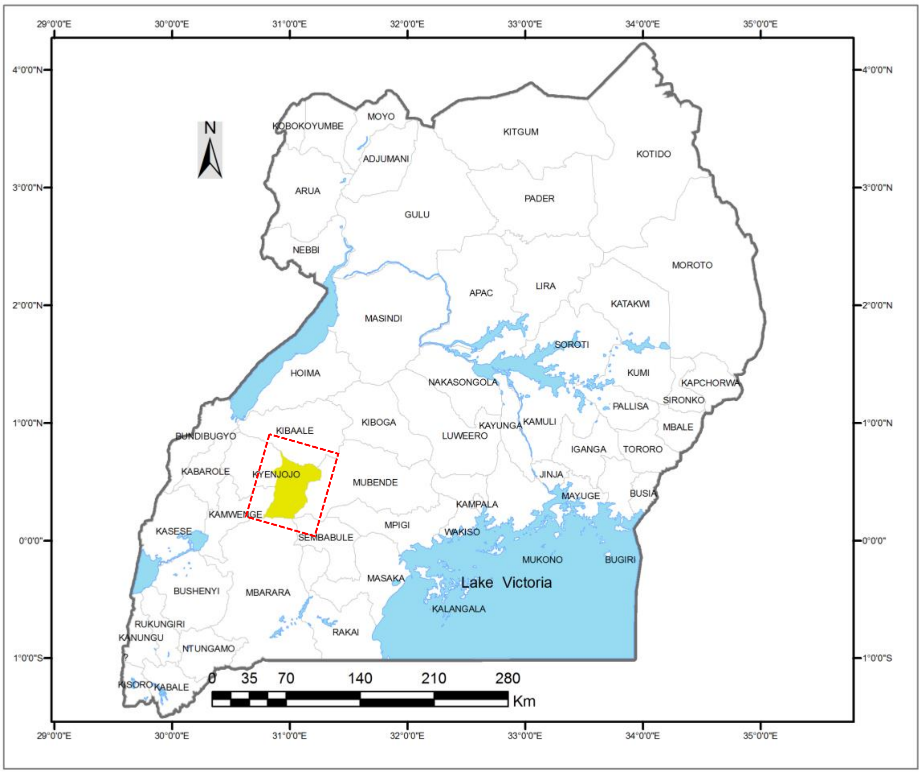


Figure 20: Area covered under the Block Treatment in Kabarole District - 1991

Prior to the project, need was identified to benchmark the infection levels. This led to examination of 987 heads of cattle with 62 being positive with trypanosomiasis providing an infection rate of 6.28% (MAAIF Report –

Prevalence survey of trypanosomiasis in Kyegegwa, Kyaka County, Toro district, 1991). The mass treatment performed on 3,225 heads of cattle in Kyegegwa reduced the prevalence of animal trypanosomiasis from 6.28% to 0.08% by end of the second year.

d. Tsetse control project in South Western Uganda:

The project was funded by the United Nations Capital Development Fund (UNCDF), UNDP and FAO. The main activity was ground spraying for Tsetse Control using Dieldrin (Organochloride). This resulted in a 90% reduction in tsetse apparent density in about 2,500 km^2 of south western Uganda (COCTU report 1992).

e. Tsetse Control project in Buvuma Islands – 1991:

The International Atomic Energy Agency provided support worth $310,000 in 1991 in the form of training, expert missions and equipment in sustenance of tsetse control in Uganda. This was to support an integrated approach to tsetse eradication including use of sequential aerosol technique (**SIT)**. During this project a tsetse colony was initiated. As a result tsetse population in Buvuma Islands were reduced by 79% (Ogwal and Kangwagye, 1991). This project was short-lived due to logistical limitations.

f. Farming in Tsetse Control Areas (FITCA) - 1997-2008:

The FITCA project funded by the European Union (EU) at cost of Euros 9.4 million, was also implemented in south eastern Uganda (Gidudu et al., 2005). The main objective of the project was to control tsetse flies through community-based technologies integrated with appropriate agricultural practices in the tsetse infested areas. During this project, 600 zero-grazing units were introduced, 84,000 cattle received prophylactic treatment (*Samorin*) and 27,000 pyramidal traps were deployed causing a tsetse population reduction of over 75% in the intervention areas (Gidudu et al., 2005). Activities to reduce the transmission of HAT (sleeping sickness) included; active and passive surveillance, treatment of diagnosed cases, active patient follow up, provision of drugs and equipment to sleeping sickness treatment centres and emergency active surveillance by mobile teams in outbreak areas.

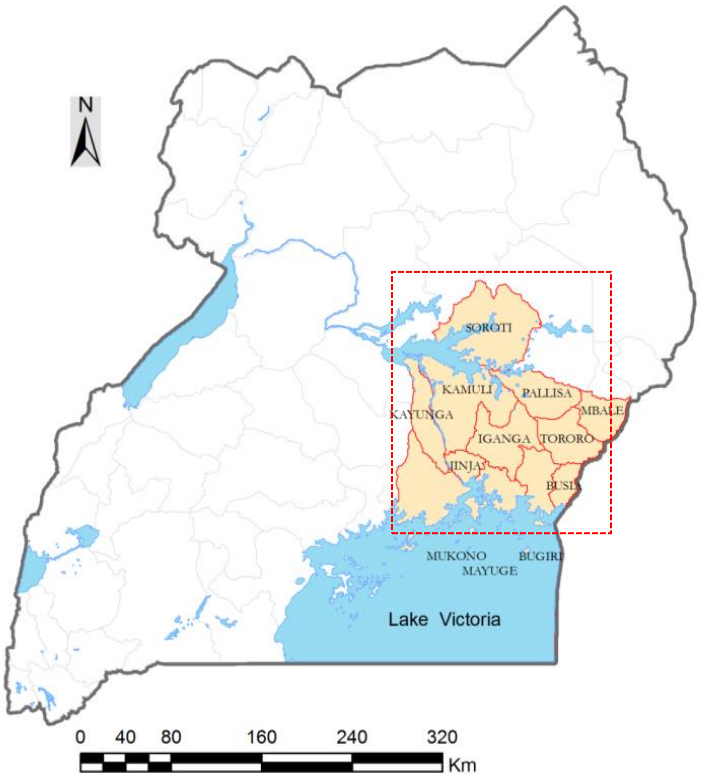


Figure 21: Area covered under the Farming in Tsetse Control Areas (FITCA) project:

Additionally, over 500 farmer groups were supported to establish community spray associations for application of insecticide on livestock, while 64 farmer groups were supported to undertake animal traction. FITCA project was implemented in 32 high risk sub-counties selected from 12 districts within South Eastern Uganda. The implementing districts were; Kamuli, Mukono, Kayunga, Iganga, Bugiri, Soroti, Mbale, Jinja, Mayuge, Busia, Pallisa and Tororo.

Prior to the implementation of the project, a baseline survey for HAT and AAT was conducted. Results from the survey were used in prioritising subcounties for action into three levels i.e. (i)Level I - High incidence of sleeping sickness, (ii) Level II - Areas with prevalence of nagana greater than 12% and medium incidence of HAT and (iii) Level III - Areas of prevalence of nagana between 6 - 12%. For the prioritized subcounties, the main tsetse and trypanosomiasis control methods involved block treatment of cattle with Isometamidium chloride (mass treatment) and Diminazene acecurate (clinical) by District staff; while tsetse fly control was by trapping and insecticide spraying of cattle. This effort as observed from Figure: 22, reduced AAT from 6.6% in 1999 to 4.52% in 2004 in the 12 FITCA districts (Gidudu et al, 2005).

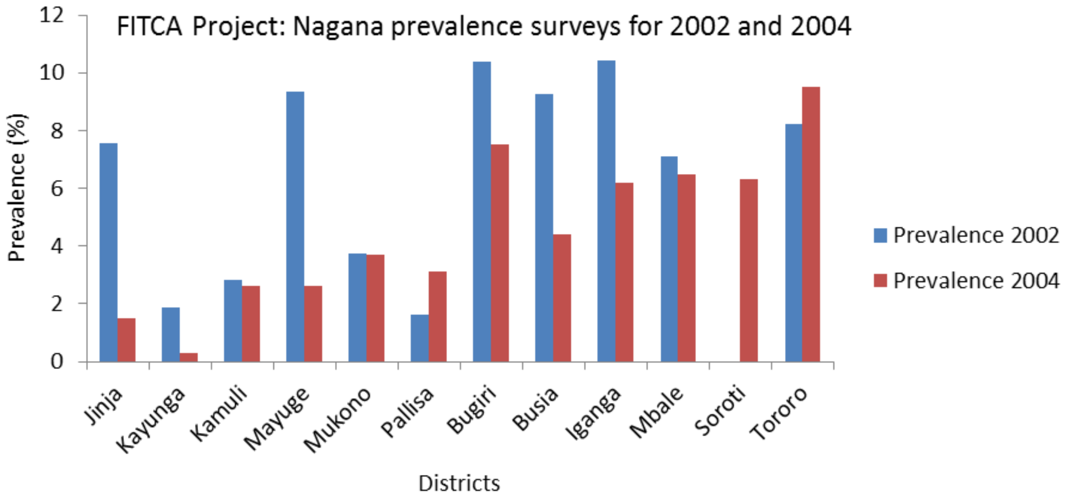


Figure 22: Nagana prevalence under FITCA project (2002-2004)

2.4.6 Period 2000-2013

a. National livestock productivity improvement project (NLIPP) - 2001-2010.

The **NLIPP** project funded by ADB and GOU, had a small component of tsetse control which was implemented mainly in the Teso region, as a contribution towards halting the merger of the two forms of sleeping sickness. The project's overall objective was poverty reduction through improved livestock productivity and enhanced livestock marketing in order to increase the availability of high quality animal products for both the domestic and export markets. The specific objective was to improve livestock productivity and marketing in the cattle corridor that was consistent with the Government of Uganda (GOU) policies of sustainable economic growth with regional equity and poverty reduction. The Project had five main components: (i) Livestock restocking & genetic improvement, (ii) Improved livestock health status, (iii) Improved livestock water supply and forage resources, (iv) Improved livestock marketing and information systems and (v) Project coordination.

Through the improved livestock health status component, the project supported tsetse control activities in the tsetse infested districts of Teso sub-region by providing logistics in the form of 200 bicycles, 34,000 tsetse traps, 600 litres of Deltamethrin insecticide and 12,000 doses of Isometamedium chloride. Beneficiary districts were; Amuria, Bukedea, Budaka, Katakwi, Kaberamaido, Soroti, Kumi, Pallisa, Sironkho and Kamuli.

In addition, the project produced and distributed sensitization /awareness materials on tsetse flies and tsetse-borne diseases (nagana and sleeping sickness) in the farming communities of the **NLIPP** project area. In the framework of sharing roles, the beneficiary districts recruited and trained field workers to assist in the deployment, monitoring and maintenance of tsetse traps. The trained field workers were facilitated with bicycles for easy outreach to communities.

b. Stamp out Sleeping Sickness project: 2006 - 2010.

The stamp out sleeping sickness (SOS) project was implemented by the Makerere University Faculty of Veterinary Medicine (now called COVAB) supported by University of Edinburgh and funded by DFID,IK and CEVA. It came as a response to the threat of merger of the two forms of sleeping sickness (*T.b.rhodesiense* and *T.b.gambiense*).

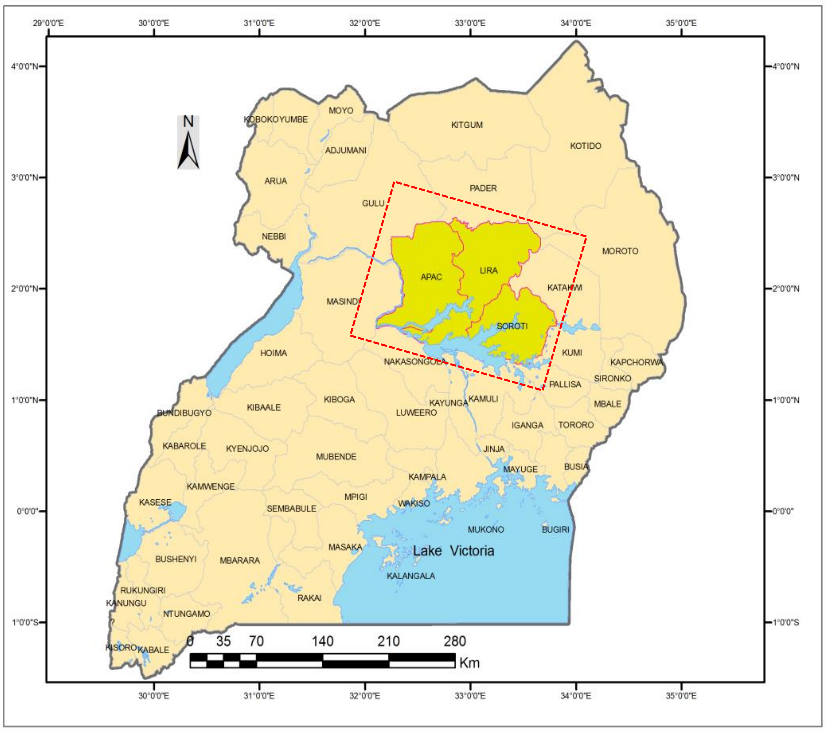


Figure 23: Area covered under the Stamp Out Sleeping sickness (2006 – 2010)

Hence activities were based within the interphase districts of Lango and Teso sub-regions i.e. Otuke, Alebtong, Lira, Kole, Apac, Amolatar, Dokolo, Kaberamaido, Soroti and Serere districts. Activities involved mass treatment of cattle and spraying of livestock using the restricted application protocol. Over 500,000 cattle were treated with trypanocidal drugs and sprayed with Deltamethrin (Table: 9).

The Stamp out Sleeping Sickness (SOS) programme and its diffusion of restricted application protocol (RAP) of insecticide treatments for cattle, using Vectocid, was based on a public-private partnership which was also expected to build sustainable institutions / structures that would deliver the needed veterinary drugs and services for farmers sustainably. The consortium involved the following partners:

- IK Investment Partners (IK), a pan-European private equity firm, which provided project management support as well as funding through IKARE, a registered charity;
- CEVA Santé Animale, a veterinary pharmaceutical company which donated both the trypanocides and provided technical know-how;
- The Faculty of Veterinary Medicine at Makerere University (COVAB), which provided professional expertise and students to undertake the initial intervention;
- The Coordinating Office for the Control of trypanosomiasis in Uganda (COCTU);
- University of Edinburgh, Centre for Infectious Disease Control providing monitoring and evaluation for the operation.
- Uganda’s Ministry of Health (NSSCP) and
- Uganda’s Ministry of Animal Industries and Fisheries (MAAIF).

The successes scored by the SOS were attributed to;

- Presence of an exceptional inter-sectoral co-ordination on trypanosomiasis control within the Ugandan government
- Properly packaged and well understood threat of disease merger by all stakeholders.

- Existence of a strong and longstanding network of relations between the major stakeholders, within which research information could be transmitted
- Readiness of major private sector players to become involved, as a form of corporate social responsibility, and to see the project managed with flexibility very different from the style of traditional development donors.

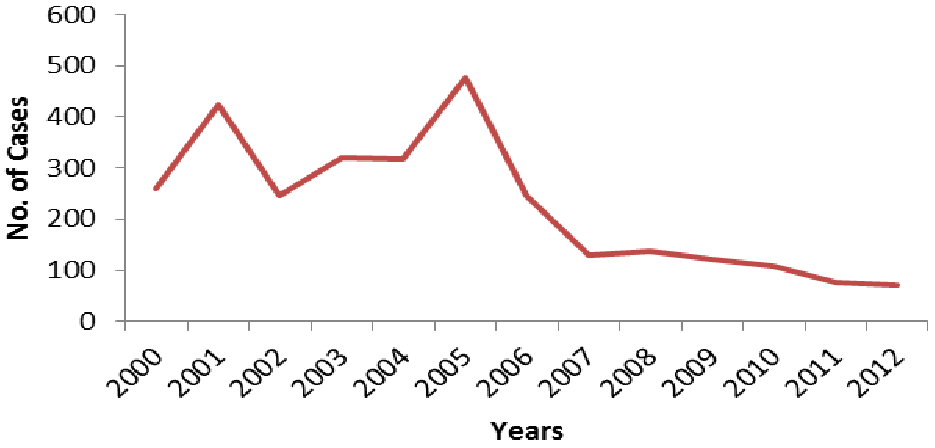


Figure 24: Trend of HAT (T.b.rhodesiense) (2000 – 2012) in Uganda
Source: Data obtained from NSSCP of Ministry of Health

Between 2000 and 2005, HAT *(T.b.rhodesiense)* was observed to spread further north to the Teso-Lango sub-region notably; Serere, Soroti, Kaberamaido and Dokolo districts. This spread was strongly linked to increased livestock and human population movements within the region due to civil strife (Wardrop, 2010). With such activities expanding to cover the entire northern Uganda, there was an urgent need to halt the highly possible merger of the two forms of sleeping sickness.

As observed in Figure: 25, Kaberamaido, Iganga and Soroti have had the highest cumulative cases of HAT since year 2000.

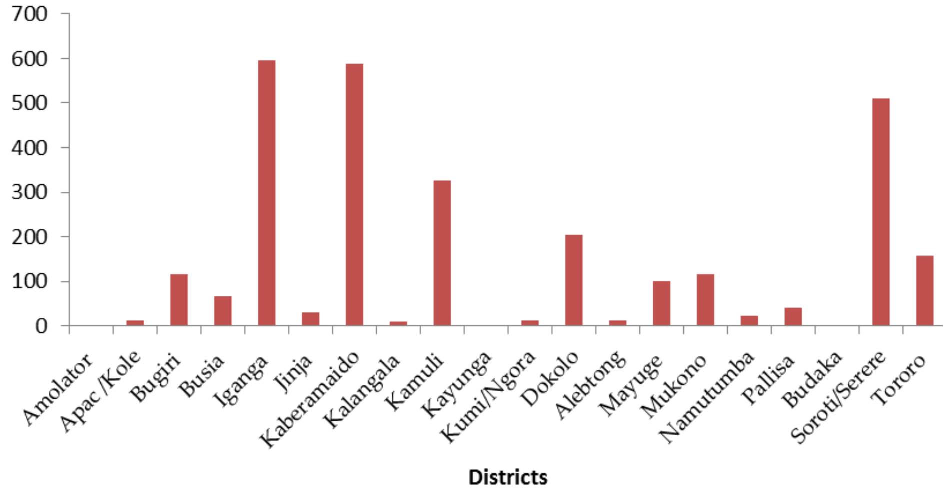


Figure 25: Cumulative HAT (T.b.rhodesiense) cases per district of Uganda
Source: Data obtained from NSSCP of Ministry of Health

Table 9, Numbers of cattle sprayed during SOS project

Date	Districts covered	Number sprayed
1st spray: October to December 2006	Amolatar, Apac, Dokolo, Kaberamaido, Lira	172,444
2nd spray: November 2006 to January 2007	Amolatar, Apac, Dokolo, Kaberamaido, Lira	134,980
3rd spray: April to July 2007	Amolatar, Apac, Dokolo, Kaberamaido, Lira	225,605
Partial retreatment: May 2008	Kaberamaido and Dokolo	31,486
		564,515

Source: SOS project documents

Based on the results from cattle parasitological monitoring and the discovery of some new sleeping sickness cases, it was decided that cattle in some parts of Dokolo and Kaberamaido districts would need to be treated again ('partial retreatment').

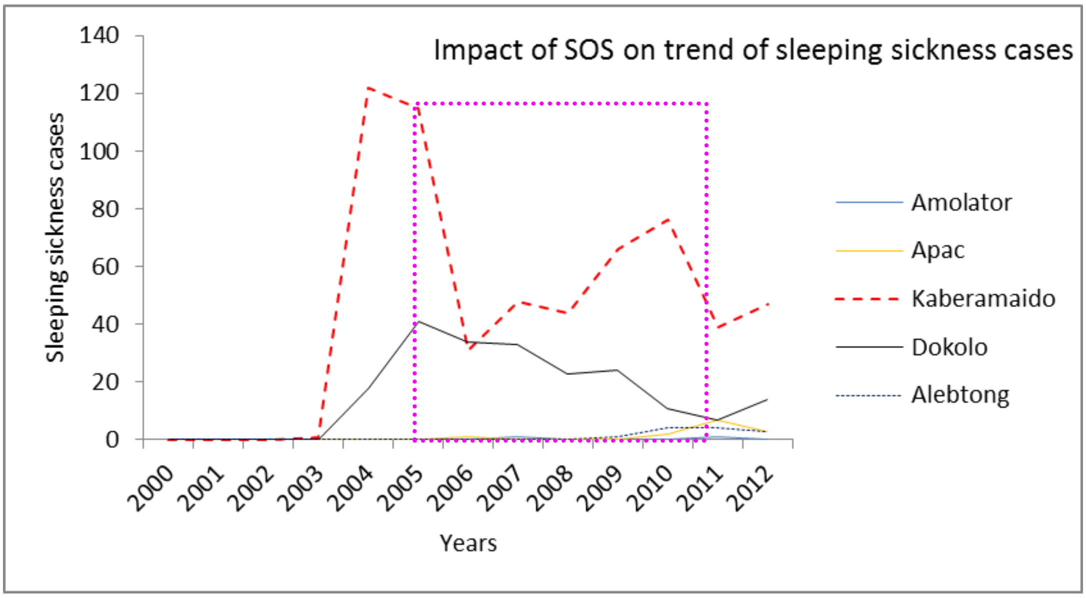


Figure 26 Impact of SOS on sleeping sickness trend

Table: 9, Shows that the effective period of intervention by SOS was from October 2006 to July 2007. From the HAT graph (Figure: 26) specifically for the intervention districts, there was an overall gradual reduction in HAT cases for Kaberamaido district from 115 cases (2005) to only 31 cases (2006) presumably due to the SOS intervention. Other districts were equally responsive to the interventions. Overall the intervention reduced the chances of possible merger of the two forms of sleeping sickness at the time.

Overseas funding for the SOS programme was provided by its private partners, IK/IKARE and CEVA Santé Animale. IK/IKARE provided the initial money for running costs in the field and for monitoring of cattle populations. CEVA provided the trypanocides which were used in the initial mass treatment of cattle and then the Vectocid for spraying cattle to control tsetse and ticks.

c. **Sustainable tsetse and trypanosomiasis free areas (PATTEC): 2006 - 2011.**

This project was funded by ADB at a value of $4 Million and was expected to free 40,000 km^2 area of tsetse flies. 16 Intervention districts were selected from SE Uganda and these were; Kalangala, Mukono, Kayunga, Buvuma, Jinja, Buikwe, Iganga, Luuka, Namutumba, Kaliro, Kamuli, Buyende, Mayuge, Bugiri, Namayingo and Wakiso. Activities involved tsetse control using insecticide treated pyramidal traps (114,000 traps), live bait technology or pour-on application on cattle (1,021,966 head of cattle), treatment of livestock, active screening and treatment of people for sleeping sickness. The Project had a component on tsetse mass-rearing for SIT application and also offered capacity building to key staff in various tsetse operational fields (STATFA Project Completion Report, 2012).

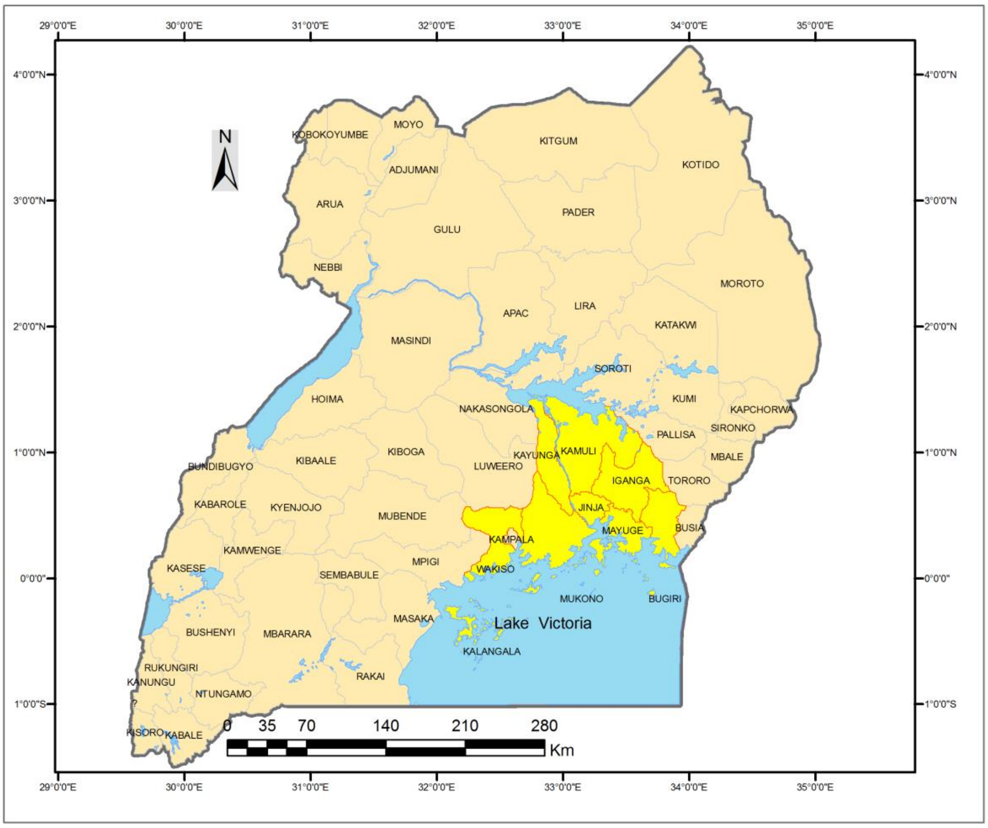


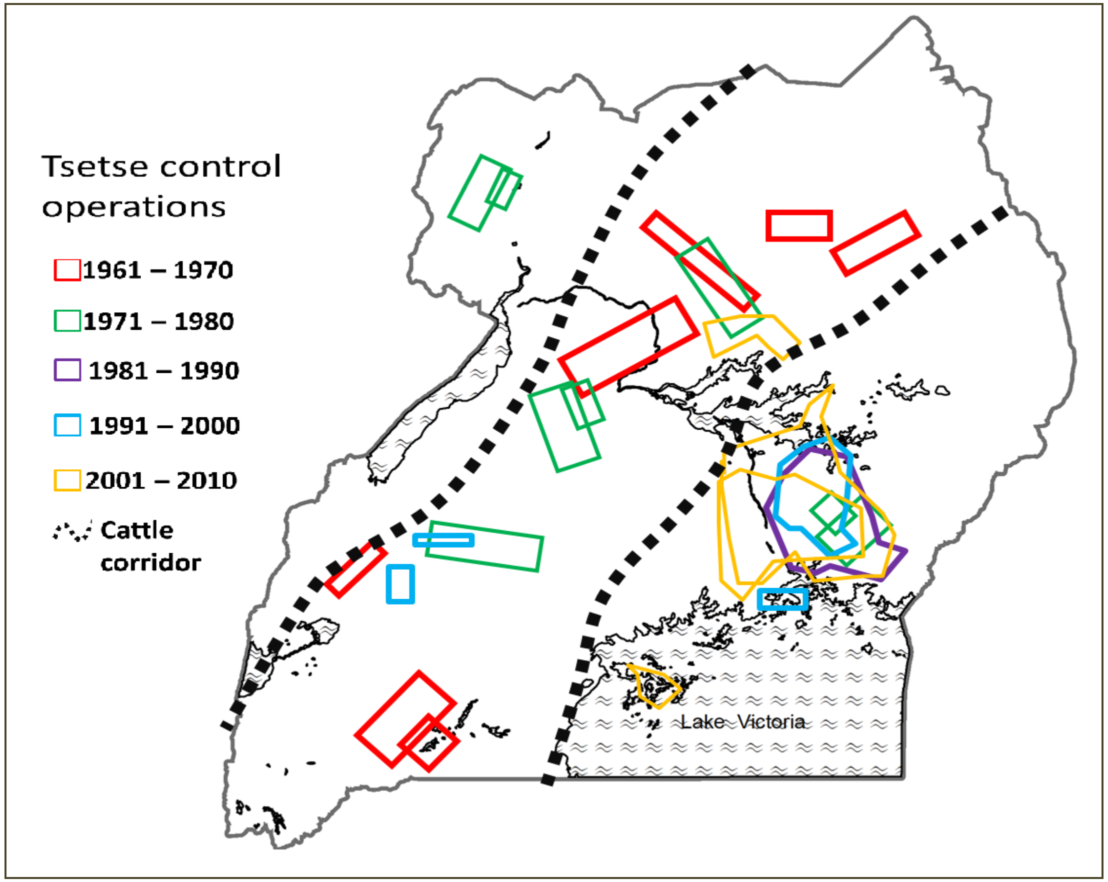
Figure 27: Area covered under the Sustainable tsetse and trypanosomiasis free areas (PATTEC): (2006 -2011)

As a result of implementing that project, the overall tsetse challenge in intervention zones was reduced from 1.8 to 0.49 flies per trap per day. Trypanosomiasis (AAT) prevalence was reduced from 4.5% (2004) to 0.8% (2010). HAT prevalence in intervention districts reduced from 138 cases (2006) to only 03 cases (2010) overall. The project eventually operated in only 12,500 Km^2 covering only high tsetse challenge Subcounties from 16 districts due to technical and logistical setbacks.

2.5 Discussion

Currently, many tsetse scientists are engaged in discussions about the merits and demerits of various tsetse vector control options. Major considerations are being weighed against the options that are environmentally friendly, cost-effective and above all sustainable (Grant, 2001; Shaw et al. 2013).

Methods and approaches applied during the various decades under review varied from one another. The period 1960-1970 witnessed interventions which were highly targeting the removal of either the tsetse habitats or the tsetse fly itself. This was done through carrying out; total or selective bush clearing, game elimination through hunting, game eviction, cattle evacuation, maintenance of tsetse pickets, application of insecticide on cattle, and ground spraying using insecticide (Dieldrin-3%). Despite the negative impacts on the environment, tsetse control methods like game elimination and bush clearing enabled the reclamation of over 4000km^2 of land from Ankole region (SW Uganda) alone. Other chunks of land were reclaimed using bush clearing and ground spraying from the same region (Table: 3). Such land has since been used for large scale livestock keeping. Unfortunately, this approach led to the destruction of vast natural forested and concomitant wildlife in SW Uganda. Several countries / communities have since rendered such approaches environmentally dangerous to both animal and human health and thus discouraged them.



Period	Est. expenditure (USD $)
1961-1970	1,144,900
1971-1980	510,330
1981-1990	4,781,075
1991-2000	1,014,974
2001-2010	14,905,770
Total	**22,357,049**

Figure 28: Distribution of tsetse and trypanosomiasis control projects in Uganda over the past 50 years

Table 10 Estimation of investments in research and control of Tsetse/HAT/AAT for the T.b.rhodesiense focus (SE Uganda) over the past 50 years.

South east Uganda (Busoga, Bukedi, Buganda, Bugishu, Teso and Lango)

Major Period	Actual period / Duration	Region / districts**	Control method	Target Tsetse species	Operational area (Km^2)	Estimated cost of operation (USD)
1960-1970	N/a	N/a	N/a	N/a	11,449	1,144,900
1970 - 1980	1971 – 1979 (9yrs)	Busoga/Bukedi	Ground spraying (*Dieldrin)*	*G. f. fuscipes & G. Pallidipes*	1,005***	100,500
1980 – 1990	1980	Busoga/Bukedi	Aerial spraying (*Endosulfan*)	*G. f. fuscipes*	2,157**	409,830
	1982	Busoga/Bukedi	Aerial spraying (*Endosulfan*)	*G. f. fuscipes*	1,380**	262,200
	Jan-March 1988	Busoga (Jinja & Luuka)	Aerial spraying (*Endosulfan*)	*G. f. fuscipes*	600**	114,000
	Jun-Aug 1988	Busoga (Kamuli & Iganga)	Aerial spraying (*Endosulfan*)	*G. f. fuscipes*	925**	180,375
	Jan-April 1990	Busoga (Mayuge, Bugiri & Iganga)	Aerial spraying (*Endosulfan*)	*G. f. fuscipes*	1,100**	214,500
	1987 - 1989	EEC supported project in Busoga (Iganga & Kaliro)	Trapping (16,000 pyramidals) integrated with intensive HAT surveillance, block treatment of livestock and pour-on application	*G. f. fuscipes*	3,300	4,010,000
1990 – 2000	1990 - 1993	EEC/French supported trapping project in Busoga / Bukedi (Kamuli, Iganga and Tororo)	Trapping (30,000 pyramidals) integrated with HAT surveillance	*G. f. fuscipes*	5,850	670,000
	1991-1992	IAEA project in Buvuma Islands	Integrated approach including SIT experimentation	*G. f. fuscipes*	20	300,000
	1990 - 1991	AU-IBAR supported emergency HAT surveillance and treatment along Kenya-Uganda border	Emergency HAT surveillance and treatment along Kenya-Uganda border. 15000people screened, health education and	*G. f. fuscipes*	280	44,974

			limited trapping			
	1997 - 2008	**FITCA** project in 32 subcounties selected from 12districts (Iganga, Jinja, Kamuli, Mayuge, Mukono, Kayunga, Mbale, Busia, Pallisa, Tororo, Bugiri and Soroti)	Trapping (27,000 pyramidals) integrated with HAT surveillance & treatment, 84,000 cattle treated with samorin and spraying of livestock by over 500 farmer spray associations	*G. f. fuscipes*	10,500	10,070,000
2000 - 2010	2000 - 2013	**NLIPP** project in Teso region (Kaberamaido, Soroti, Kumi, Amuria, Katakwi, Pallisa, Bukedea and Kamuli)	Provided tsetse and trypanosomiasis control inputs (200bicycles, 34,000traps, 600litres of *Deltamethrin* insecticide, and 12,000doses of *Isometamedium chloride*	*G. f. fuscipes*	N/a	360,000
	2006 - 2010	**SOS** emergency intervention project in Teso/Lango region (Kaberamaido, Lira, Dokolo, Apac, Amolator and Serere)	Over 500,000cattle treated with trypanocidals and sprayed with *Deltamethrin (RAP).*	*G. f. fuscipes*	10,000	475,770
	2006 - 2011	**STATFA (PATTEC)** project-operated in 12,500 Km^2 covering only high tsetse challenge Subcounties from 16 districts in Busoga region and limited part of Buganda	Used insecticide treated pyramidal traps (114,000 traps), pour-on application on 1,021,966 head of cattle, treated livestock, undertook active screening and treatment of sleeping sickness cases.	*G. f. fuscipes &* *G. Pallidipes*	12,500	4,000,000

*****_Data has been adjusted to take care of the current districts and their respective names (2010)_

***Estimates based on the 1988 average SAT costs per square kilometre i.e.(\$190/Km^2)*

**** Estimates based on the previous average costs for ground spraying per square kilometre i.e.(\$100/Km^2)*

Aerial spraying of insecticides (SAT) was applied in the 1980s to halt the HAT epidemics experienced in many counties of Busoga region. Such a method is considered to be area-wide as it enables wider coverage over a shorter period of time compared to other tsetse control approaches. The method is effective once applied properly and with the right insecticides (Adam, 2013; Kgori, 2006). The evidences provided in the HAT trends for Busoga region is a clear manifestation that this method is effective. Unfortunately the approach is expensive and most times it is carried out with support of donor community (Shaw et al. 2013).

The use of toxic and persistent substances like Dieldrin during ground spraying for most of 1960-1970, has received denunciations. Dieldrin is a synthetic chemical used to kill insects at the time. It was the main chemical available for vector control during the period 1950-1970 (Sserunjoji, 1973). Fortunately many countries have since signed treaties against its use. Dieldrin was banned for use in most countries in 1980s due to environmental concerns and negative impact on human health. The chemical is acutely poisonous and highly persistent in the environment. Depending on climatic conditions, 3%Dieldrin once applied can remain persistent in the environment for up to 10 years (Sserunjoji, 1973). Other than its environmental setbacks, the application of Dieldrin to tsetse resting places greatly kills the tsetse flies. Outside Uganda, Dieldrin has been used to control tsetse flies in countries like; Botswana (1974-76), Central Africa Republic (1960-65), Kenya (1967 -1970), Mali (1963-1968), Mozambique (1949-1970), Nigeria (1954-1970), Tanzania, Rwanda and Zambia (FAO,1993).

Endosulfan insecticide was the chemical used during most of the aerial spraying (SAT) in the sleeping sickness epidemic counties of Busoga in the late 1980s and early 1990s. This chemical proved effective in killing the tsetse flies as demonstrated in the various entomological monitoring results.

Over time there has been a tendency by central governments to divulge from the direct responsibility of implementing tsetse and trypanosomiasis interventions. This is reflected in the **Decentralisation policy of Uganda (1997)** which relegated functions of disease and pest control to local governments (districts). This was a mistake as diseases and vectors do not respect political / administrative boundaries. The engagement of local authorities to address the tsetse problem is usually met with lack of the needed resources to implement such programmes. During the period 1980-2000 there was a move to directly get the local communities involved in handling the tsetse and trypanosomiasis problem as primary beneficiaries. This has commonly been referred to as community participation. The participatory role of the community will always depend on levels of motivation at hand. For the application of trap technology, communities have proved essential. That is why many refer to the use of pyramidal traps as a community-based programme. The pyramidal trap was preferred because; (i) It was relatively cheap ($3), can be used with or without impregnation and above all it is easy to set-up in the field (Lancien 1991; Okoth, 1991).

Tsetse fly encroachment upon previously reclaimed areas constituted a major problem in most of the areas were success had been registered. For south western Uganda, were tsetse had been eradicated from several blocks, the tsetse re-invasion was from several fronts. In the South west along the Uganda / Tanzania border *G.morsitans centralis machado* continued to infiltrate the 75 km x 5 km tsetse barrier zone along the Uganda-Tanzania border (Kangwagye, 1987). This tsetse infiltration into the barrier zone was unfortunately facilitated by illegal grazing of cattle within the tsetse barrier zone and watering of animals on the Kagera river. In most cases barrier zones provided ideal grazing grounds due to usually overgrown grasses and being tsetse free. Re-invasion remains as an obstinate problem where local eradication has been claimed but extensive neighbouring areas cannot be attended to due to logistical or political reasons (Rogers et al 1994). Under all circumstances tsetse barriers (artificial or natural) must be regularly maintained to guarantee and sustain the achievements.

In Uganda, if the cost of capital equipment is disregarded and only recurrent expenditure is considered (i.e. wages, allowances, vehicle operation, uniforms, insecticides etc.), the ground spraying costs using Dieldrin were estimated at £100 per km^2. This cost including capital expenditure costs for majority of ground spraying programmes, was met by Government of Uganda with support from USAID.

During the period 1980-1990, the intensive trapping programme estimated the initial expenditure on purchase and deploying about 8 traps in an area of 1km^2 at £50 per km^2. However it was presumed that with expansion of activities to cover wide blocks the cost of maintenance and replacement of traps would decrease to £20 per km^2. This implies that, with trapping using pyramidal traps, the heaviest investment is at the inception of the programme and thereafter the cost to sustain control activities decreases drastically. With ground or aerial spraying it has been demonstrated that every 2-3 years an equal amount of money would be required to implement the control activities like at the beginning of the programme.

Based on the SOS project mass treatment campaigns conducted in 2006/7, the average cost for treating and spraying an animal was below $1. Such treated animals would be protected for 6months and above all would act as mobile tsetse traps. This cost-effective approach halted the highly expected merger of the two forms of sleeping sickness at the time. However this mode of intervention depends on the availability of adequate livestock in the target area and being grazed over unrestricted space. Besides that, in the wet season the spray will not provide protection for that long.

Using one phase of SAT application carried out in 1990 in Busoga region as an example; a total of 39,475 litres of Endosulfan insecticide was sprayed over total flight duration of 193 flying hours and with 26,000 litres of aviation fuel consumed (Kangwagye et al. 1991). An average dosage rate of 8.5 litres km^{-2} was sprayed depositing an average 25.5 g /ha of active ingredient. All these inputs generated a round cost of \$190 per km^2 of sequential aerosol application.

In all the past tsetse and trypanosomiasis interventions discussed, it is evident that impacts were measured based on set protocols for each component (medical, entomological and veterinary). The observable decline in sleeping sickness cases, reduction in tsetse apparent densities (FTDs) and reduction in animal trypanosomiasis prevalence were the primary measures for success.

One of the key benefits from this work is the creation of an archive of the reports identified in this study. Plenty of reports / records concerning previous tsetse and trypanosomiasis control operations were retrieved from different places. All these have been assembled and stored carefully. A strong recommendation has been made to the COCTU administration to have all the retrieved information stored electronically.

2.6 Conclusion

The problem of re-invasion will remain a big challenge until the question of how to enduringly maintain the barrier zones is answered. This trait will always reverse the successes. Examples of monotonous tsetse and trypanosomiasis projects in the same zones, one after the other, are a clear manifestation that a historical problem exists. Thus, the tsetse and trypanosomiasis problem will remain a major problem constraining agricultural productivity and production in Uganda. For purposes of ensuring population protection, an integrated approach, preferably at community level, should be considered. This would involve use of conventional methods for control of tsetse flies (using traps and livebaits), treatment livestock and regular screening of humans for sleeping sickness.

CHAPTER 3: AN ENTOMOLOGICAL SURVEY OF THE LAKE VICTORIA BASIN TO ASSESS TSETSE PRESENCE AND APPARENT DENSITIES.

3.1 Overview

An entomological survey was conducted in the Lake Victoria basin of Uganda in 2010 to assess systematically the distribution and abundance of tsetse flies. A total of approximately 5,000 biconical traps where laid in an area of 40,000 km^2 covering 16 districts. The findings indicate that *G. f. fuscipes*, a species of the riverine group, was widely distributed across the surveyed area. Whilst *G. Pallidipes* was detected in a few isolated locations in Eastern Uganda, close to the border with Kenya. The analysis of land cover exhibited an important association between *G. f. fuscipes* and vegetation mosaics having a cropland-component. This observation confirms the adaptability of some species of riverine tsetse flies to anthropized landscapes, a trait having vast epidemiological ramifications in the transmission of human and animal trypanosomiasis.

3.2 Introduction

In 2010 the Government of Uganda embarked on a project of tsetse elimination within the framework of the Pan-African Tsetse and trypanosomiasis Eradication Campaign (PATTEC). In order to guide tsetse suppression interventions and monitor their effectiveness, epidemiological, entomological, socio-economic and environmental datasets were collected. The present chapter recapitulates and discusses the methods used and findings of the entomological survey. In particular, entomological datasets are statistically analysed and matched against standardized land cover maps for Uganda to explore the associations between tsetse fly derived parameters and different landcover variables.

3.3 Materials and methods

3.3.1 Study area: Geography and Tsetse problem

The area under study, as shown in Figure: 29, is predominantly a lake basin stretching for approximately 50 to 100 km from the Lake Victoria shoreline, comprising of 19 districts out of the current 112 total districts of Uganda (2013). It is a region characterized by high rainfall of 1000-1500 mm per annum, with two markedly distinct seasons (Figure: 11) and with dense vegetation for most of the un-inhabited zones. The major form of livelihood is through agricultural production. Mixed farming, combining crops and livestock provides a livelihood for the vast majority of the population (Cecchi et al. 2009). This area forms part of the national trypanosomiasis corridor. Due to the widespread presence of tsetse flies, over 3 million people and 1.5 million cattle in the region are at risk of contracting trypanosomiasis (Entomology-MAAIF report 2013). Notably, however, this region also holds a significant number of important towns and cities, including Kampala the capital city. This makes the region economically significant and certainly holds a lot of potential for the country's national development.

Agriculture is an important activity in the Lake Victoria basin. It is the main economic activity as it employs over 80% of the region's population. The majority of this population lives in rural areas and thus earns its living through direct interaction with the natural environment (farming, fishing, forestry, mining, hunting etc). Approximately 70% of the agro-based people are engaged in crop farming while about 15% are engaged in livestock keeping. It should be observed that while close to 95% of this region is arable, the majority of the farming is under the subsistence type of agriculture, highly dependent on natural rainfall and applying poor farming technologies. The burden of disease heavily affects the livelihoods of the rural communities in this region.

Selection of the study area was based on historical knowledge of tsetse presence and high HAT prevalence in the region (Figures: 8, 9 & 10). This region has been an endemic area for HAT and AAT for over 100yrs (Mbulamberi 1989). Over one million people have lost their lives so far, and currently over three million people are at risk of acquiring the disease in this SE Uganda region alone (NSSCP-MoH, 2002). It is further estimated that over $30 million has since been injected in the region to avert the tsetse and trypanosomiasis crisis but with limited long-lasting success (COCTU report, 2013). Above all, this region holds a strong economic potential for the country's development. Hence the need to free it from the tsetse burden.

3.3.2 Entomological survey

The exact extent of the survey area was delineated taking into consideration historical knowledge of the tsetse distribution. Local knowledge was supplemented by tsetse prediction maps (Wint et al. 2000 & 2001). In total, an area of 40,000 km^2 was targeted for the entomological survey (Figure: 29). The survey was designed to cover the entire project area but with extra focus on the known suitable tsetse habitats. Data was collected during a rainy season (March - May) of 2010.

Once demarcated, the study area was divided into four survey blocks (Figure 30), which were in turn subdivided into approximately 400 grid cells of 10 × 10 km using consolidated methods (leak et al 2008). At the planning phase, the precise positions of traps within each grid cell were determined assisted by a Geographic Information System (GIS), with the technical input of experienced entomologists. The choice of the survey sites was guided by a range of GIS layers, including tsetse prediction maps (Wint, 2001), land cover (FAO Africover dataset for Uganda, 2000), accessibility, topography, and a hydrological network.

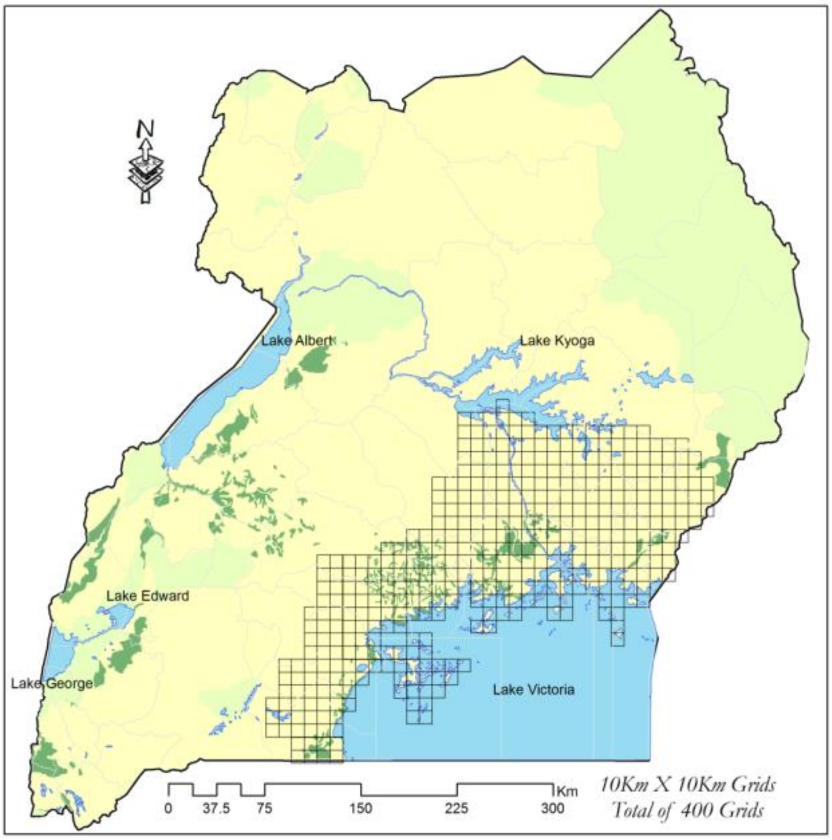


Figure 29 Location of study area of 40,000km2 (400 grid cells)

These layers enabled the pre-determination of ideal trapping sites guided by easy accessibility and habitat suitability factors. In total, approximately 5,000 trapping sites were pre-determined, corresponding to an average of 13 traps per grid cell. These determined points were considered representative for the tsetse situation assessment in the study area. These points were entered into all the calibrated GPS machines and navigation functions enabled. Field teams were guided to the pre-determined points for trap deployments by the GPS machines.

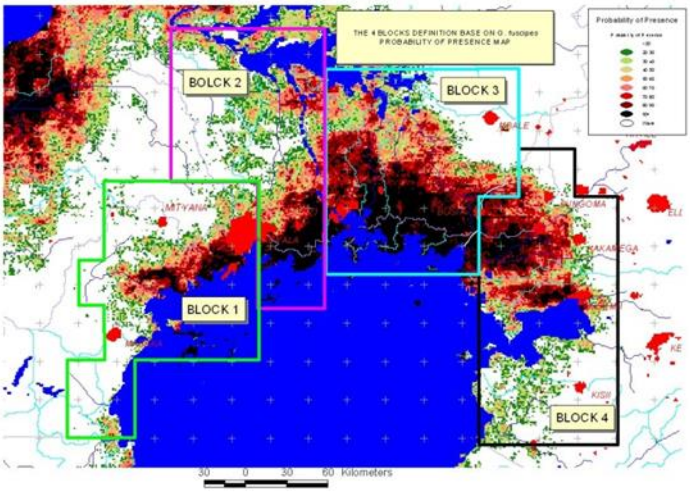


Figure 30 Tsetse survey blocks

Biconical traps (FAO Tsetse survey manual, 2009) were used in this survey, and geo-referencing of the exact trap positions in the field was carried out using hand-held geographical positioning system equipment (GPS Garmin 76). Trapping at each site lasted 72 hours. The parameters recorded in the entomological survey sheet included: trap code, latitudes, longitude, altitude, vegetation type around the trap site, start date / start time, end date / end time of the sampling, species, number of females, males and flies of un-identified sex, number of other biting insects (Entomological survey sheet in appendix 111). Males and females were separated, characterised and counted. Data from hand-written, hard-copy survey sheets were entered into a geospatial database. Several parameters for analysis purpose were computed from the collected entomological survey data, and these are considered in section 3.4 of this chapter.

Survey teams were formed at district level and were composed of five people namely; district entomologist, driver and three experienced entomological assistants. Such team composition was preferred since districts have such staff structures. The entomologists were trained for five days on the technical and operational standards for the assignment.

(a) shows the biconical trap used during entomological survey

(b) shows the live tsetse flies in a cage

(c) Is a display of harvested tsetse flies in an open collection bag

Figure 31 (a-c) Trap setting and tsetse harvest

3.3.3 Land cover

The patterns of association between tsetse densities and vegetation cover were explored using the FAO Africover dataset for Uganda (FAO Africover,Uganda, 2000). FAO-Africover provided general-purpose datasets of land cover that were derived from visual interpretation of remotely-sensed digital images (Landsat). Medium-resolution satellite datasets (15/30 m) enable land cover to be mapped at a reference scale of 1: 200,000. The original Africover map of Uganda includes 67 land cover categories. As that level of thematic detail was deemed excessive for exploring tsetse habitat suitability, a simplified version was used which only includes 20 classes (Cecchi et al. 2008). The simplified legend was generated from the original 67 classes by thematic aggregation, using the standard rules of the Land Cover Classification System (Di Gregorio, 1998 & 2005). Detail in the description of

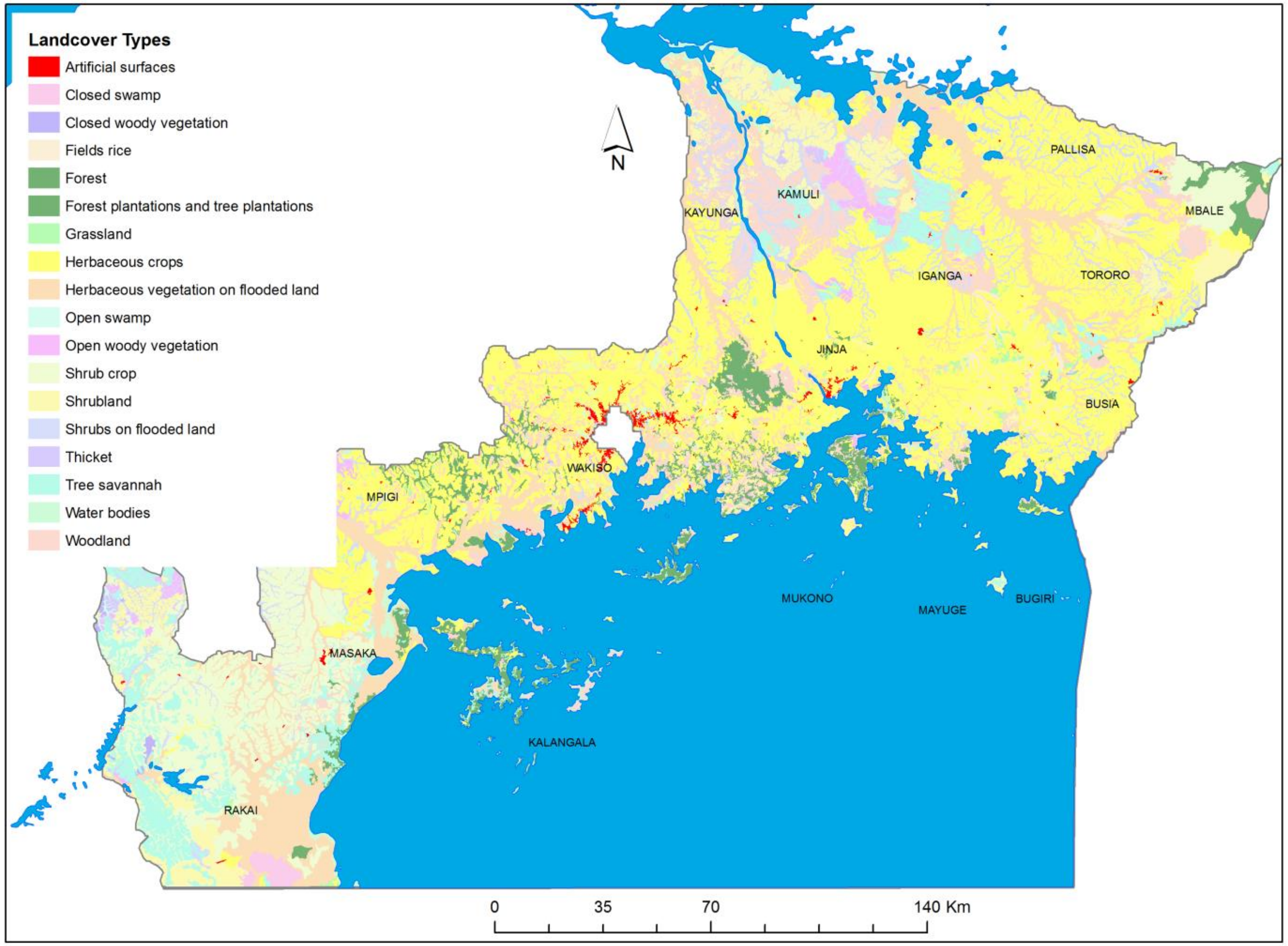


Figure 32 Landcover map for study area (FAO-Africover, 2000)

natural vegetation was retained in the process, so as to maximize the relevance of the simplified legend for tsetse habitat mapping. Table: 11, shows the area sharing by the different land cover types. Only 18 classes (Figure 32) out of the 20 for Uganda were relevant to the area under study.

Table 11: Computed areas and percentages of all landcover types in study area

Landcover Type	Total land area(km2)	Area as a Percentage (%)
1. Artificial surfaces	139	0.27
2. Closed swamp	120	0.24
3. Closed woody vegetation	43	0.08
4. Fields rice	174	0.34
5. Forest	1289	2.54
6. Forest and tree plantations	21	0.04
7. Grassland	106	0.21
8. Herbaceous crops	10542	20.74
9. Herb veg on flooded land	3491	6.87
10. Open swamp	160	0.31
11. Open woody vegetation	510	1.00
12. Shrub crop	2673	5.26
13. Shrubland	1717	3.38
14. Shrubs on flooded land	1706	3.36
15. Thicket	31	0.06
16. Tree savannah	1831	3.60
17. Water bodies	23764	46.76
18. Woodland	2506	4.93
Totals	**40,000**	**100%**

3.3.4 Data analysis

Firstly, using the tsetse catch data, maps depicting the tsetse distribution and abundance across the study area are generated using ArcGIS 9.1 tool.

Secondly, entomological data is analysed quantitatively to determine (a) trap performance, (b) tsetse densities (FTD), (c) fly sex-ratios and (d) species ratios. Thirdly, an analysis to better understand the association between tsetse catch data (FTD) and the land cover types was performed. This involved determination of correlation coefficients and application of linear regression ($y=b_0 + b_1x$) particularly to understand if performance of tsetse traps was associated with type of landcover and tsetse densities. In this case, tsetse densities (FTD) were considered as dependent variable while trap performance was taken as an independent variable. Trap performance is the ratio of positive traps to total number of traps deployed in each landcover type. It acts as an indicator of landcover suitability to tsetse fly habitation. R-square (R^2) which is the Coefficient of Determination was computed and used to assess how well the resultant regression equation fitted the data.

Due to spatial resolution of the land cover data used, a buffer distance of 1000m was found appropriate and applied on each of the trap-sites to allow computation of required parameters. For each individual buffer, respective areas for the various landcover types were computed in square kilometres. These computed areas were used as input data for the linear regression application and also computation of correlation coefficients. Finally, these tsetse point data were compared with existing modelled *G. f. fuscipes* data (Wint, 2001) by simple overlays to compare and establish relationships in results.

3.4 Results

A total of 5,287 Biconical traps (Figure: 31a) were used for trapping tsetse flies during the survey, distributed over a ground area of 40,000 km^2.

Analysed results indicate that tsetse flies were trapped in only 28.8% of the sampling sites. In total, 14,899 tsetse flies were caught. *G. f. fuscipes* was the dominant species (females=7,138, males=7,271 and 108 as unidentified sex) accounting for 97% of the total catch (Table: 13). *G. Pallidipes* contributed only 382 flies (females=221 and males=161 flies) there by accounting for 3% of total catch (Table: 13). The highest individual trap harvest for *G. f. fuscipes* was realised in Kalangala Islands within lake Victoria with the striking figure of 695 tsetse flies in 72 hours (FTD= 231). For *G. Pallidipes* the highest performing trap raised 187 tsetse flies over and above the 94 *G. f. fuscipes* which were also caught in the same trap

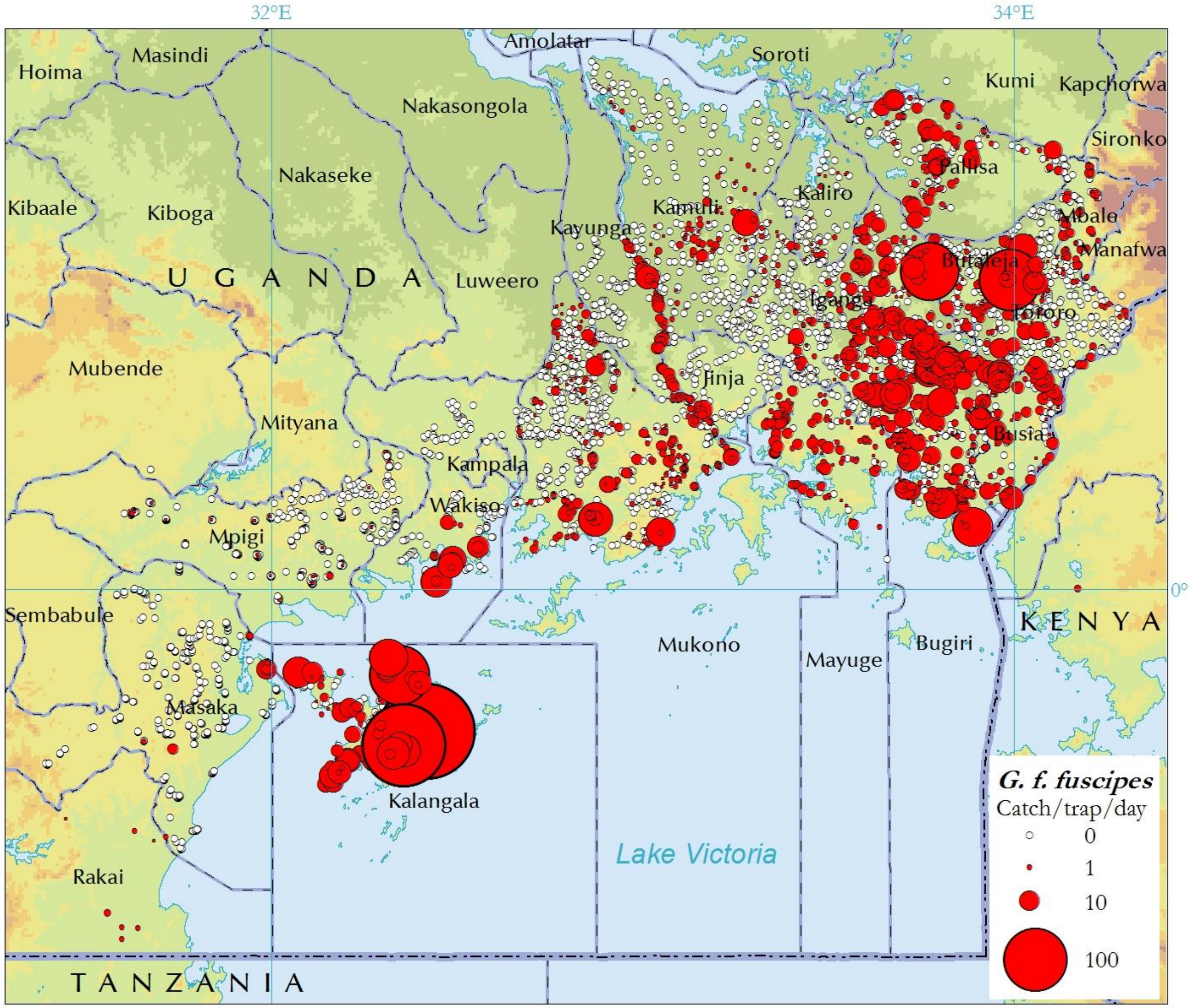


Figure 33 Distribution of trap sites and tsetse apparent densities (*G. f. fuscipes*) based on survey data

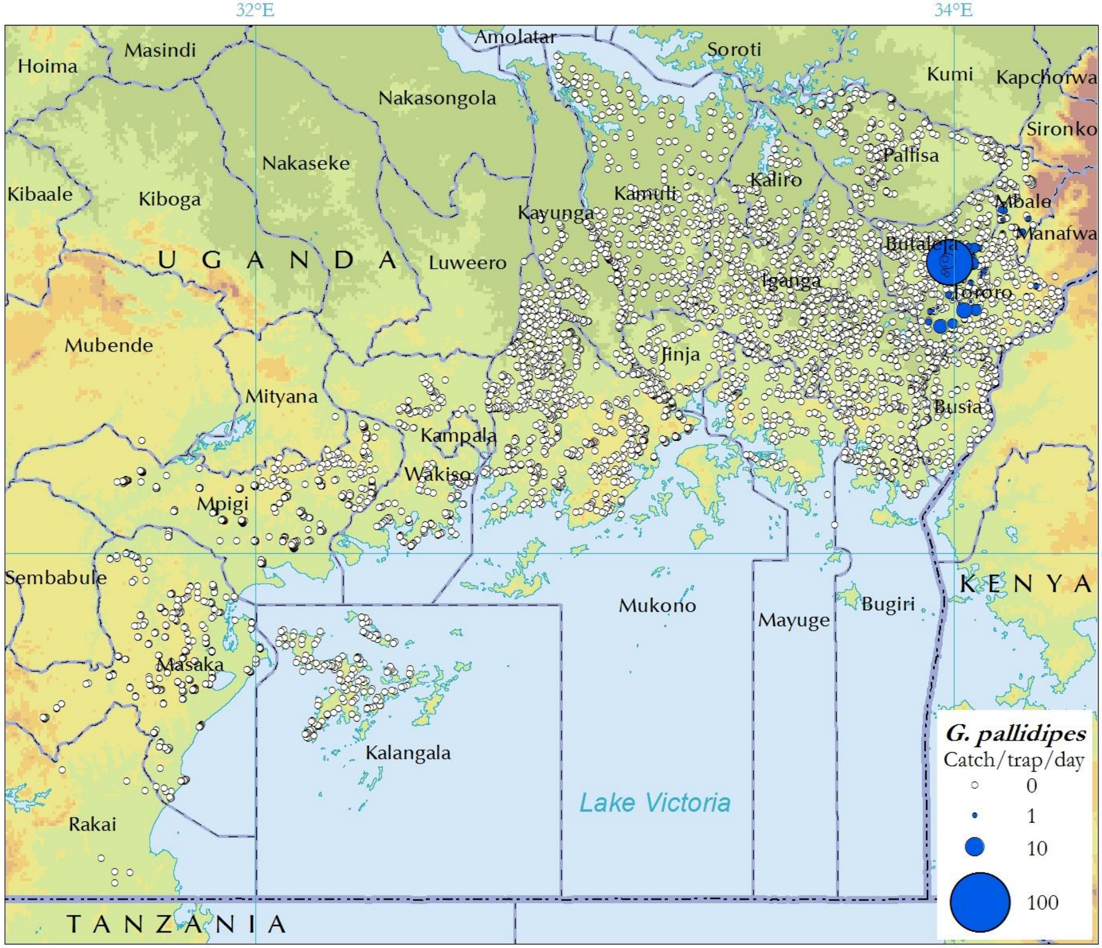


Figure 34 Distribution of *G. Pallidipes* based on survey data

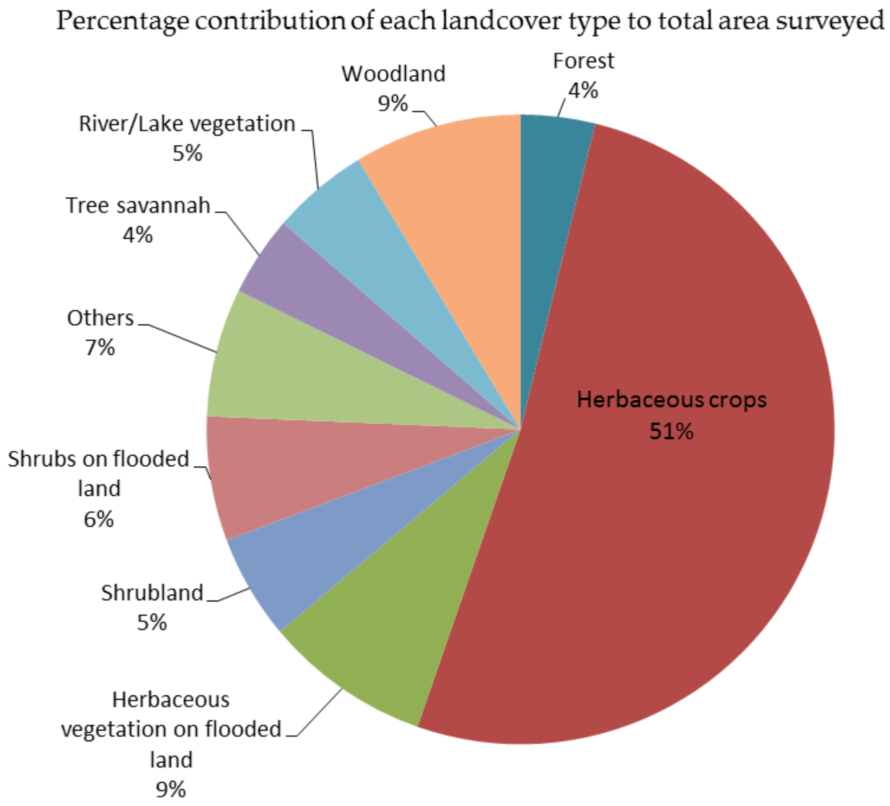


Figure 35 Percentage contribution of each landcover type to the effective total area surveyed

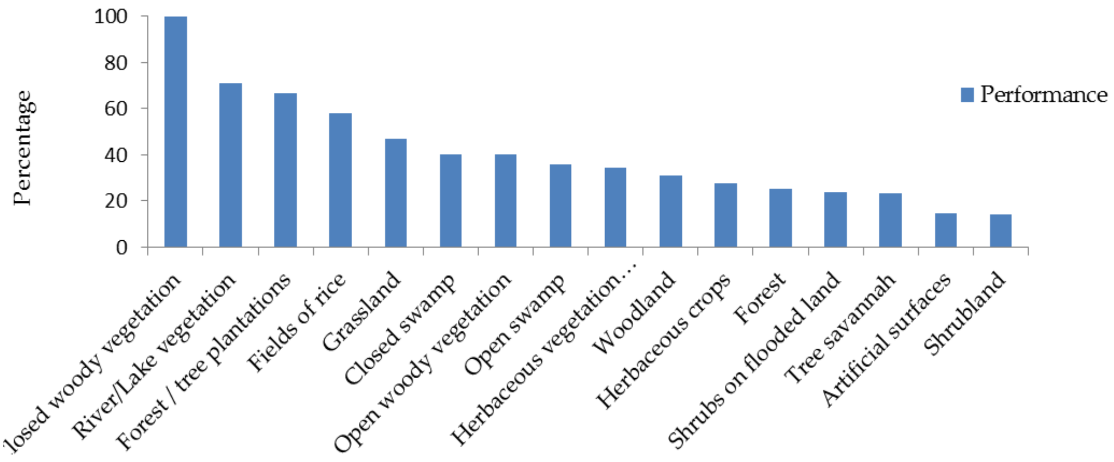


Figure 36 Trap performance in each landcover type

Note: Thickets and forest tree plantation were excluded from analysis because of their very small sizes.

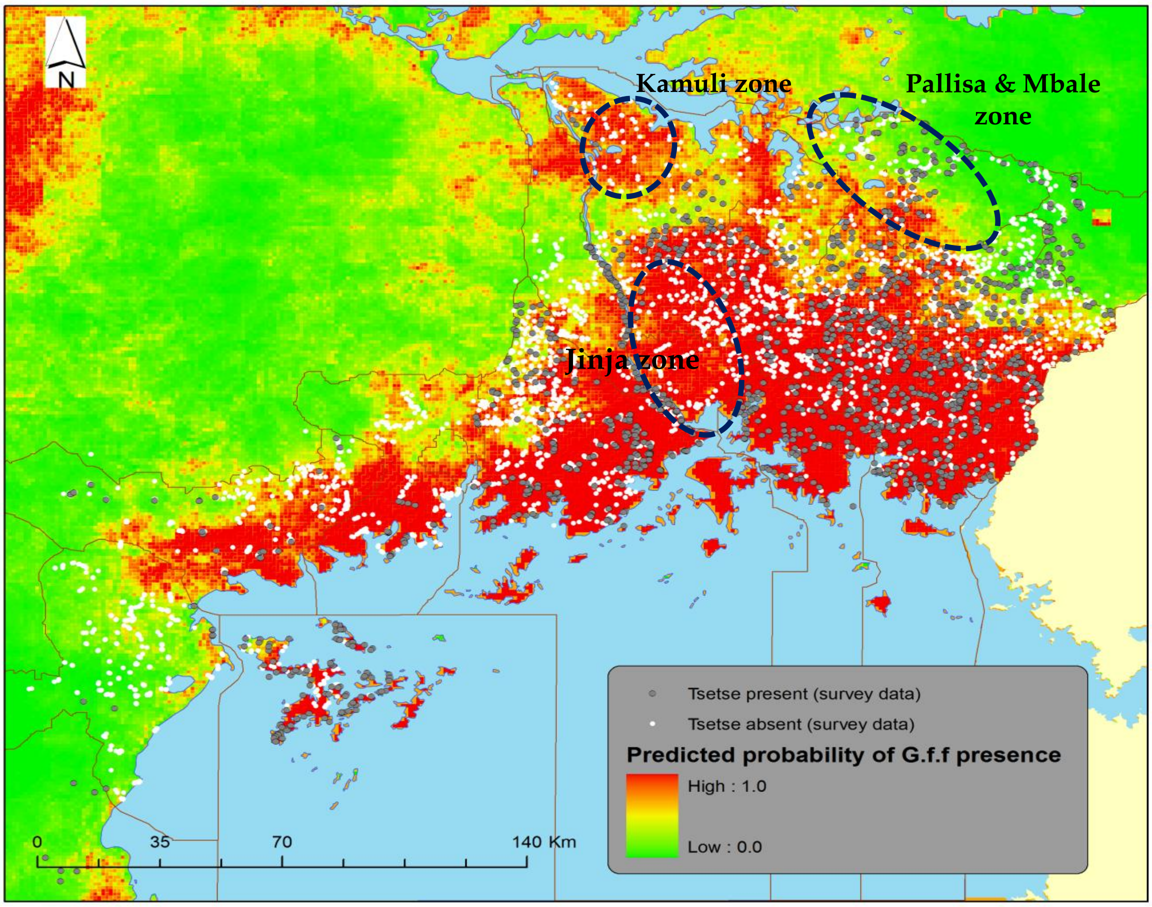


Figure 37 Comparing the survey findings with G. f. fuscipes prediction data (Wint, 2001) using overlay method

within 72hours. Overall the proportion of males to females for the two species was 1:1. Tsetse fly catches fluctuated between 0 and 9 flies/trap/day (FTD). The lowest FTD (0.016) was registered in Mpigi district, while the highest (231) was in Kalangala Islands. The computed apparent fly density for the entire surveyed area was 0.939. Figure: 33 indicates that *G. f. fuscipes* was visible in all districts surveyed unlike *G. Pallidipes* which was visible in only three districts namely; Tororo, Busia and Mbale (Figure: 34).

Computed entomological parameters like; trap performance, number of flies per trap per day (FTD), number of traps deployed, number of positive traps, area surveyed (Km^2) etc.

Table 12: Summary table for Entomological results per district

	Districts	No. of grids	Traps deployed	*G. f. fuscipes*		Un identified sex	*G. Pallidipes*		Average FTD (all flies/traps deployed/day)	Others
				Females G. f. f	Males G. f. f		Female	Male		Biting flies
1	Mukono/Buikwe	50	798	464	555	8	0	0	0.429	1783
2	Jinja	12	66	44	15	0	0	0	0.298	0
3	Kayunga	26	216	278	245	0	0	0	0.807	1812
4	Iganga/Luuka	23	314	254	219	0	0	0	0.502	442
5	Mayuge	14	118	234	259	0	0	0	1.393	49
6	Kamuli/Buyende	35	296	139	117	0	0	0	0.288	0
7	Namutumba	10	166	234	671	0	0	0	1.817	257
8	Bugiri	15	498	1575	1953	66	0	0	2.406	409
9	Manafa/Mbale	19	120	91	68	0	10	7	0.489	175
10	Pallisa/Budaka	15	242	268	325	0	0	0	0.817	497
11	Masaka	36	404	46	35	0	0	0	0.067	127
12	Mpigi	34	721	29	5	1	0	0	0.016	1664
13	Kalangala	10	172	2692	2114	29	0	0	9.370	639
14	Rakai	20	97	13	6	0	0	0	0.065	5
15	Wakiso	28	388	242	136	0	0	0	0.325	751
16	Kaliro	8	89	17	11	0	0	0	0.105	300
17	Busia	11	115	147	257	0	0	1	1.174	628
18	Tororo	15	300	269	197	0	211	153	0.922	1027
19	Butaleja	8	167	102	83	4	0	0	0.377	249
	Totals	**389**	**5287**	**7138**	**7271**	**108**	**221**	**161**	**0.939**	**10814**

Table 13: Results from the Tsetse - Landcover data analysis

Land cover type	Total area Km^2	No. of traps deployed	Total number of positive traps	Trap performance (%)	No. of flies per trap per day (FTD)	Effective area surveyed (Km^2)	Effective Area surveyed (%)
Grassland	106	15	7	47	0.42	46.99	0.57
Tree Savannah	1,831	269	62	23	1.13	346.56	4.21
Thicket	31	1	0	0	0	4.40	0.05
Shrubland	1,717	115	16	14	0.13	271.57	3.30
Forest	1,289	302	76	25	2.02	321.98	3.91
Woodland	2,506	391	121	31	0.93	727.45	8.84
Closed woody	43	3	3	100	0.20	5.24	0.06
Open woody	510	55	22	40	0.44	112.97	1.37
Herbaceous vegetation on flooded land	3,491	462	158	34	0.89	720.78	8.76
Shrubs on flooded land	1,706	503	119	24	0.37	536.99	6.52
Closed swamp	120	15	6	40	0.53	10.06	0.12
Open swamp	160	59	21	36	1.92	45.95	0.56
Artificial surfaces	139	21	3	14	0.30	33.31	0.40
Fields rice	174	83	48	58	2.14	110.03	1.34
Herbaceous crops	10,542	2,436	676	28	0.71	4332.02	52.64
Shrub crop	2,673	134	8	6	0.05	181.24	2.20
Forest plantations and tree plantations	21	3	2	67	2.11	4.66	0.06
Riverine/Lake vegetation	23,764	134	95	71	7.07	418.70	5.09
Total	**40,000**	**5000**	**1443**	**29**	**0.98**	**8230**	**100**

A total of 10,814 other biting flies (none-tsetse) were captured in the different traps (Table: 13). These were mainly in the family of stomoxys, haematopota and tabanidae. There was an observed response of species sharing in each trap, with an existence of more biting flies than tsetse flies in each trap.

Overall percentage of effective landcover surveyed is 16% (i.e 8,230/5,0823). Out of the effective landcover surveyed, 51% of the survey was conducted in herbaceous crop, 4% in forest and 5% in riverine (river/lake vegetation) among others. The effective landcover considered as surveyed is that which is within 1km from any trap-site within the study area. That is, only land falling within the buffers is considered as effectively surveyed land (8,230Km^2).

3.5 Discussion

The focus of the study was to collect entomological data and use it to characterise the presence and abundance of tsetse species in the greater northern Lake Victoria basin. Similar studies leading to the production of sub-national tsetse distribution maps have been conducted (Adam et al. 2011; Bouyer et al. 2010; Vreysen et al. 2014; Leak 1998; Alemu et al. 2007).

Several tsetse sub-species have been known to exist in this basin, including, *G. f. fuscipes*, *G. Pallidipes* and *G.brevipalpis* (Ford and Katondo, 1971; Wint, 2001). Among these tsetse sub-species, *G. f. fuscipes* has been known to be most wide spread in the Victoria basin and consequently of economic significance in the region (Wint, 2001). *G. Pallidipes* has been known to be present in South Eastern Uganda (Ford and Katondo, 1971 and Wint, 2001). *G.brevipalpis* is a species of low economic significance. This is largely due to its inability to transmit HAT but with a capacity to transmit AAT among wild and domestic animals. This inability is attributed to the fact that this species takes rather few meals from bovids, whereas other species (*G. Pallidipes* & *G. f. fuscipes*) living in the same area take more meals from bovids (FAO, 1982). Results from the survey were able to confirm the presence of *G. f. fuscipes* and *G. Pallidipes* within the study area.

G. f. fuscipes was observed to be widespread over most of the surveyed areas, occupying its traditional ecological zones, depicting the continuity between the two ecological zones (i.e. lake Kyoga and lake Victoria) as illustrated in the studies on levels of genetic differentiation for *G. f. fuscipes* species in Uganda (Beadell et al, 2010). Isolated substantiation of *G. f. fuscipes* was also realised in Rakai and Masaka districts on the south-westerly wing of the Lake Victoria basin. This isolated evidence came as a unique finding, demystifying the thought that *G. f. fuscipes* was absent in those parts of the country (Entomology Report, MAAIF 1999).

G. Pallidipes was trapped from only 35 sites out of the total of over 5000 trap-sites and registered the highest FTD of 62.3, from Tororo district, one of its historical territories (Okoth et al 1991; Robinson et al 1997). Such figures suggest presence of unique ecological conditions necessary for high infestion of *G. Pallidipes* in those locations. Though in very small numbers and in isolated pockets, two other districts (Busia and Mbale) showed catches of *G. Pallidipes*. These two districts are geographically linked to Tororo district. Busia lays to the south while Mbale (Manafa) lays to the east of Tororo district. A comparison of these results with the available maps for estimated distribution of *G. Pallidipes* (Ford and Katondo, 1971; Wint, 2001) shows that there has been a shift in geographical coverage and habitat occupation by the *G. Pallidipes* over time. However, Berrang-Ford (2013) contends that failure to adequately capture *G. Pallidipes* (especially from historical territories) should not be used as an indicator of confirmed absence of *G. Pallidipes* from the region. Rather, a consideration of applying more sensitive trapping tools be made in line with the fact that *G. Pallidipes* is a species which highly avoids humans and humanised landscapes (Leak, 1999). Further, the capacity of field technical staff doing tsetse taxonomy need to be enhanced so as to improve sensitivity in species identification. On a regional perspective, there appears to be a common zone for *G. pallidipes* transiting into western Kenya. Thus the control efforts ought to be from both fronts i.e. Kenya and Uganda. There may be high chances of re-invasion if efforts are not jointly and simultaneously handled.

Presence of *G.brevipalpis* in the study area was not confirmed as it was not caught at all. The failure to catch even a single *G.brevipalpis* in the region could be attributed to the type of trap used and its sensitivity to certain tsetse species (Vale et al. 1979). Alternatively, this could also be a result of increased human interference in the region causing fly instability and eventual retreat (Rogers, 2003). *G.brevipalpis* lives in low land evergreen forests where optimal atmospheric conditions can be maintained (Cecchi et al 2008). Such landscapes exist in the districts of Mukono, Mayuge, Kayunga and Iganga within the study area. Given the trend of increasing deforestation experienced in many parts of the study area, *G.brevipalpis* could easily retreat or disappear completely from the region (Rogers, 2003). This case is not much different from the *G. f. fuscipes* which was predominantly known for preferring to live close to water bodies, in linear forested vegetation along rivers and lakes (Beadell et al. 2010), but only to be trapped also in cultivated herbaceous crop lands in large numbers. Cultivated lands are considered unsuitable for tsetse flies (De la Rocque et al. 2001).

The largest proportion of the survey area was composed of herbaceous crop vegetation (51%). This type of land cover is largely composed of cereals, roots/tubers, sugarcane and vegetables (Cecchi et al. 2008). In many cases such crops are intercropped with sparse trees. Such trees offer suitable conditions for the existence of *G. f. fuscipes* as resting places. Thus, it is of no surprise to discover from the survey results that trap performance and FTD from herbaceous crop vegetation were 28% and 0.71 respectively.

A substantial amount of the study area is under "forests" (4%). This is a type of land cover which is largely composed of broad-leaved evergreen trees with several canopies at heights of 5-30 m. This land cover type provides favourable conditions to the forest tsetse species (Fusca and Palpalis). Forest zones had a computed high FTD of 2.02, closest to the riverine vegetation.

Tsetse survey conducted along the shorelines or streams (water bodies) revealed a high trap performance of 71% with average FTD of 7.07. Water bodies *per se* do not hold any significant suitability for *G. f. fuscipes* habitation. However an interface of water bodies and forested vegetation (lacustrine/riverine vegetation), provides suitable conditions for *G. f. fuscipes* existence and survival (Leak et al. 2008). Such a finding confirmed the existing fact that *G. f. fuscipes* is a riverine species (FAO 1982).

Field of rice as a Landcover showed a significantly high trap performance of 58% with FTD of 2.14. This was a striking result. Such Landcover is usually dominated by rice crop and with expected zero suitability for tsetse. But the mix of such vegetation and water is reminiscent of other suitable land cover types such as swamp and seasonally flooded grassland, which could easily attract tsetse flies (Cecchi et al. 2008).

Using the landcover data (FAO, 2000), the tsetse catch data were evaluated for response to different landcover variables using the computed trap performance and FTD as variables. The linear regression analysis conducted was able to establish an association where only about 11% ($R^2=0.113$) of the FTDs observed could be explained by the status of the trap performance within each landcover type. Such a low coefficient of determination is indicative that some other factors could be at play in determining FTDs for each landcover type beyond the trap performance variable. A key point to note with FTDs is that while the traps remained for about 72 hours in the field, it took several days / weeks to have the entire survey area covered. Due to their attractive ability, initial traps can have an advantage over the traps deployed weeks later across different landcover types. Such a situation, if not well understood, can lead to wrong suppositions about the relationship between FTDs and landcover variables.

When compared with published tsetse distribution maps (Wint and Rogers, 2001) as shown in Figure: 37, the entomological survey results broadly fit the predicted probabilities for tsetse (*G. f. fuscipes*) in the region. However, this study results seem to indicate that there is an expansion of the *G. f. fuscipes* belt towards the north east specifically in Pallisa and Mbale districts. There is also evidence of disappearing *G. f. fuscipes* possibly due to intensive change in human land-uses in form of expanded sugar cane cultivation and settlement in many zones around Jinja and Kamuli districts. None the less, these findings to some extent go ahead to confirm the validity and current relevance of modelled tsetse presence/absence data (Wint, 2001) for the Lake Victoria basin.

A large number of non-tsetse flies were also trapped in the process of the survey. These are also biting flies and of interest in further understanding and explaining their possible role trypanosomiasis transmission. There is growing concern to account for the high trypanosomiasis prevalence in some areas of Uganda despite very low levels of tsetse presence. There is need to conduct studies so as to ascertain the capacity and role of these biting flies in mechanical transmission of trypanosomiasis to both humans and animals.

It is worth observing at this stage that the land cover data used for planning the tsetse survey and analysis of entomological findings was the FAO Africover dataset for Uganda of 2000. But for modelling purpose as observed in chapters 4 & 5, a more recent landcover dataset (GlobCover for 2009) was used for analysis. This was for the resolve of bringing the model outputs near to current field reality based on most recent environmental data.

3.6 Conclusion

The study undertaken confirmed that the northern Lake Victoria basin is still heavily infested by tsetse flies of mainly the *G. f. fuscipes* sub-species. *G. Pallidipes* appears to be receding to isolated sections of south-eastern Uganda while *G.brevipalpis* and any other possible species were not detected by the tools used in the entire survey area. The presence of tsetse in the districts of Rakai and Masaka comes as unique evidence and confirmation that *G. f. fuscipes* is expanding to new ecological zones. Thus, a full interpretation of these data in the form of understanding the tsetse species diversity, relative abundance and spatio-temporal dynamics can enable the accurate evaluation of options for national or sub-national tsetse control programmes. In particular, due to limited resources as always, results from such a study can be used to prioritise and target specific areas for tsetse control interventions within the affected setting. Areas identified with high tsetse densities for instance could be prioritised and consequently targeted for control operations.

CHAPTER.4: A PREDICTION OF TSETSE PRESENCE IN THE LAKE VICTORIA BASIN OF UGANDA.

4.1 Overview

Tsetse vector distribution maps are crucial in the control and management of the trypanosomiasis disease in the tsetse affected countries. Tsetse maps have in many circumstances been assembled using partial district level entomological survey reports, existing publications, sector reports and to some extent satellite-derived environmental covariates (spatial modelling). Amidst scarce resources to carry out regular full scale field tsetse surveys to update existing maps, there is need to devise inexpensive means for regularly obtaining dependable area-wide, but yet high precision tsetse information across target areas to inform and guide decision making. This study discourses this problem by applying spatial epidemiological modelling techniques (logistic regression) based on limited geo-referenced tsetse point-data (5000 locations) with satellite-derived environmental surrogates composed of precipitation, temperature, landcover, elevation and normalised difference vegetation index (NDVI) among others at the Sub-national level. The fundamental outputs include; (i) a tsetse risk map for the Lake Victoria basin of Uganda and (ii) an improved understanding of the association between tsetse presence and environmental variables. Such outputs are a scientific resource that could direct tsetse suppression interventions in Uganda.

4.2 Introduction

G. f. fuscipes is known to be present in several parts of Uganda. Its geographical extent is known to stretch from Lake Victoria's shores through central Uganda up to the West Nile region (Abila et al. 2008). In addition, *G. f. fuscipes* is present around Lakes Albert, Edward and George in western Uganda. The islands of Kalangala and Buvuma located within Lake Victoria have also been identified as accommodating *G. f. fuscipes* (Okoth el al 1991b).

The major drivers of tsetse fly habitation are temperature, humidity, rainfall, vegetation and presence of a source of blood (Leak, 1999; Rogers, 1979; Ford, 1971). This implies that tsetse flies are found in ecologically suitable habitats represented through a set of conditioning environmental variables. Such environment variables do determine: feeding behaviour; infection rates; fly movements; fly density; species-diversity; and reproduction among the tsetse flies (Leak, 1999).

Generally, tsetse thrive in areas with mean annual temperatures of 19-30°C. Temperatures below 19°C will slow down tsetse activity and general physiology (Terblanche 2008). The tsetse will be unable to move to find a host for a blood meal, leading to its starvation (Hargrove 1980). Under extreme temperatures below 10°C, tsetse will die within 3 hours of exposure. Similarly, the tsetse insect is severely affected by high temperature conditions. Precisely, tsetse flies exposed to a temperature of more than 36°C will have a 50% chance of dying within 3 hours of exposure. At a temperature more than 40°C the survival capacity is close to zero (Torr and Hargrove 1999). A temperature variation of 5°C above or below the acceptable extremes (19 – 30°C), will force the tsetse to devise a means of survival (Torr et al. 1999). Therefore, spatial information on such environmental variables can be helpful in predicting the relative distribution of tsetse flies in an area.

Tsetse distribution maps are crucial in the control and management of human and animal trypanosomiasis in affected areas. Accurate maps should ideally be based on high precision fly data derived from field investigations. In the absence of such data, tsetse distribution maps may be constructed using partial district-level entomological reports, existing publications, sector reports and modelled environmental covariates associated with suitability studies.

Given scarce resources to carry out regular field tsetse surveys, there is a need to devise inexpensive means for regularly obtaining reliable large area and high precision tsetse information across target areas to inform and guide decision makers. One way to address the problem is by applying spatial statistical modelling techniques (e.g. spatial regression analysis) using a set of tsetse field data and high precision satellite-generated environmental variables.

Regression is a statistical tool used to quantify the association between an outcome measure and predictor variables (Dohoo et al. 2010). Logistic regression, in particular, is commonly used to explain or predict a binary variable response using a set of predictor variables or covariates. Such predictive models can make use of multiple predictor variables which include; precipitation, temperature, land cover, elevation and normalised difference vegetation index (NDVI) among others. This approach has been used in the predictive mapping of various vectors and associated vector-borne diseases including malaria and Rift valley fever (Thomson, 2004), with broad applications in environmental disease risk models (Diggle et al. 2007).

The use of GIS and temporal Fourier-processed surrogates for vegetation, temperature and rainfall derived from satellite sensor data in pursuit of predicting tsetse distributions has been investigated with significant utility (Rogers et al. 1996). Further use of GIS and remote sensing in attempting to explain tsetse vector distributions is described in Rogers et al. (1993 & 1994) and Wint et al. (2000 & 2001).

Wint and Rogers (2000), at a spatial resolution of 5 km, predicted tsetse presence at the continental level using logistic regression, targeting 23 tsetse sub-species from the three major species groups (*Fusca, Palpalis* and *Morsitan*). The process applied involved fitting statistical regression models between observed tsetse data and remotely sensed predictor variables. The tsetse data used were derived from the Ford and Katondo (1977) tsetse maps, through systematic extraction of 12,000 points across the entire continent. Predictor variables included; NDVI, surface temperature, middle-infrared reflectance, vapour pressure deficit and surface rainfall (Wint and Rogers 2000).

Wint (2001), in an effort to provide more accurate tsetse maps, derived sub-continental tsetse fly distribution maps at a spatial resolution of 1 km for East Africa (Uganda) and selected parts of some countries in West Africa. This approach made use of; (i) modified Ford & Katondo presence / absence maps, (ii) 5 km-continental tsetse predictions in 2000, (iii) 17,000 data points extracted for East Africa and satellite-derived data. According to these maps, Uganda is approximately 80% tsetse infested. Although an improvement from the Wint (2000) continental version, these sub-continental tsetse distribution maps are associated with low precision. The lack of up-to-date field entomological data on tsetse counts in the model is a key point of concern while none use of land cover data as a predictor which is known to be important in determining tsetse distributions is another.

In Uganda, there is thus a need to produce more reliable and up to date tsetse distribution information, preferably at sub-national level to support decision making and improved planning of tsetse control interventions.

4.3 Study objectives

The two key objectives of this research were;

(i) To quantify the associations between tsetse presence and external factors in the study area in south-eastern Uganda and

(ii) To predict the spatial distribution of *G. f. fuscipes* in the study area.

The research is intended to provide more reliable up-to-date sub-national tsetse distribution maps derived from modelling of recent entomological survey data and remotely sensed satellite sensor data, to support planning of tsetse control and trypanosomiasis elimination interventions in Uganda.

4.4 Materials and methods

The area under study is shown in Figure 29 and is described and characterised under section 3.3.1 of chapter 3 in detail. The study area covers approximately 40% of the country's land area. The modelling steps followed are contained in Figure 38 (Process flow chart).

4.4.1 Tsetse fly data

Tsetse data were obtained from a systematic entomological survey which was conducted in 2010 to ascertain tsetse presence and abundance in the Lake Victoria basin of Uganda. A total of 5000 geo-referenced biconical traps (FAO Tsetse survey manual, 2009) were used to capture tsetse flies during the survey. Tsetse trap sites were spread uniformly over a ground area of approximately 40,000 km^2 using a grid-based system of 10 km by 10 km grid cells within the target region. Details about methodologies used in data collection, data characteristics and analysis are provided in Chapter 3. The tsetse data were used as the dependent variable in the regression modelling, while all other variables were used as independent variables.

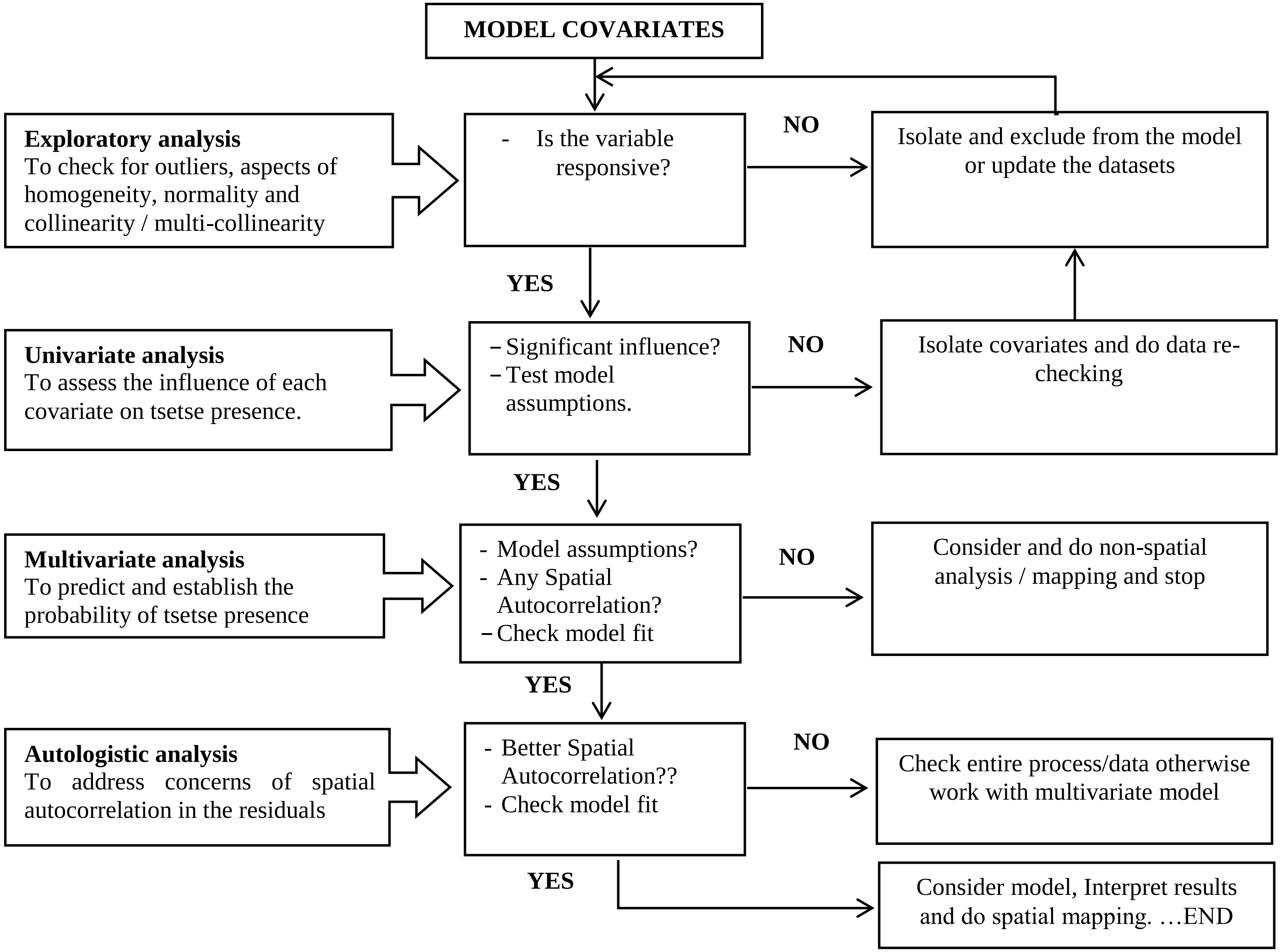


Figure 38 Process flow chart

4.4.2 Covariate data

A selection of covariates was used in the model, based on an understanding of the factors important for tsetse reproduction and survival. These included; (i) land cover, (ii) temperature, (iii) NDVI, (iv) elevation and (v) rainfall (Table: 14).

Table 14 Variables used in model construction and their sources

No.	Variable type	Data type	Spatial scale	Time scale	Source
1	Normalised difference vegetation index (NDVI)- April/May/June	Raster	~250 m	2010	(USAID) Famine Early Warning Systems Network (FEWS NET)
2	Temperature (max, min, mean)- April/May/June	Raster	(30 arc-secs (~1 km)	2010	WorldClim - Global Climate Data
3	Precipitation (Rainfall) – April/May/June	Raster	(30 arc-secs (~1 km)	2010	WorldClim - Global Climate Data
4	Elevation	Raster	(30 arc-secs (~1 km)	2010	The Shuttle Radar Topography Mission (SRTM)
5	Land-Cover	Raster	~300 m	2009	European Space Agency GlobCover 2009
6	Tsetse catch data (5033 points)	Point	N/A	2010	Field data

The landcover data (Figure: 39) used in this model were extracted from the fine spatial resolution, multi-purpose land cover dataset (GlobCover 2009). This dataset is prepared at a spatial resolution of 300 m with map projection of WGS84 ellipsoid. The land cover map is derived by an automatic and regionally-tuned classification of a time-series of global MERIS mosaics for the year 2009 (GlobCover 2009). This global land cover series is described by a legend of 22 core land cover categories in total. The region under study contained only 19 of the 22 classes presented (Table: 16). Landcover variables used in the analysis were estimated through the creation of buffers of 1000m (catchment) around each entomological tsetse survey point. Within each buffer, area percentages of the different land cover types were computed and used as the set of land cover predictor variables.

Table 15 Predictor variables used in the analyses of tsetse fly distribution and abundance including their observed maximum and minimum values in the training dataset.

Code	Name	Max value	Min value
	Rainfall(mm)		
Meteorological data surrogates	Monthly total -April	331	123
	Monthly total –May	339	79
	Monthly total –June	154	21
	Temperature (^{0}C)		
	Max Temp (April)	29.7	25.7
	Mean temp (April)	24.0	20.4
	Min Temp (April)	18.4	15.2
Meteorological data surrogates	Max Temp (May)	28.8	26.0
	Mean Temp (May)	23.5	19.8
	Min Temp (May)	18.2	14.6
	Max Temp (June)	28.6	22.0
	Mean Temp (June)	23.2	19.6
	Min Temp (June)	17.8	13.5
	Normalised difference vegetation index (NDVI)		
Vegetation surrogates	NDVI-1 (April)	0.90	0.02
	NDVI-2 (May)	0.90	0.01
	NDVI-3 (June)	0.90	0.00
Altitude	*Elevation (m)*	1412	1034
Land cover	*Land cover* (22 Classes) with details listed in Table. 16	n/a	

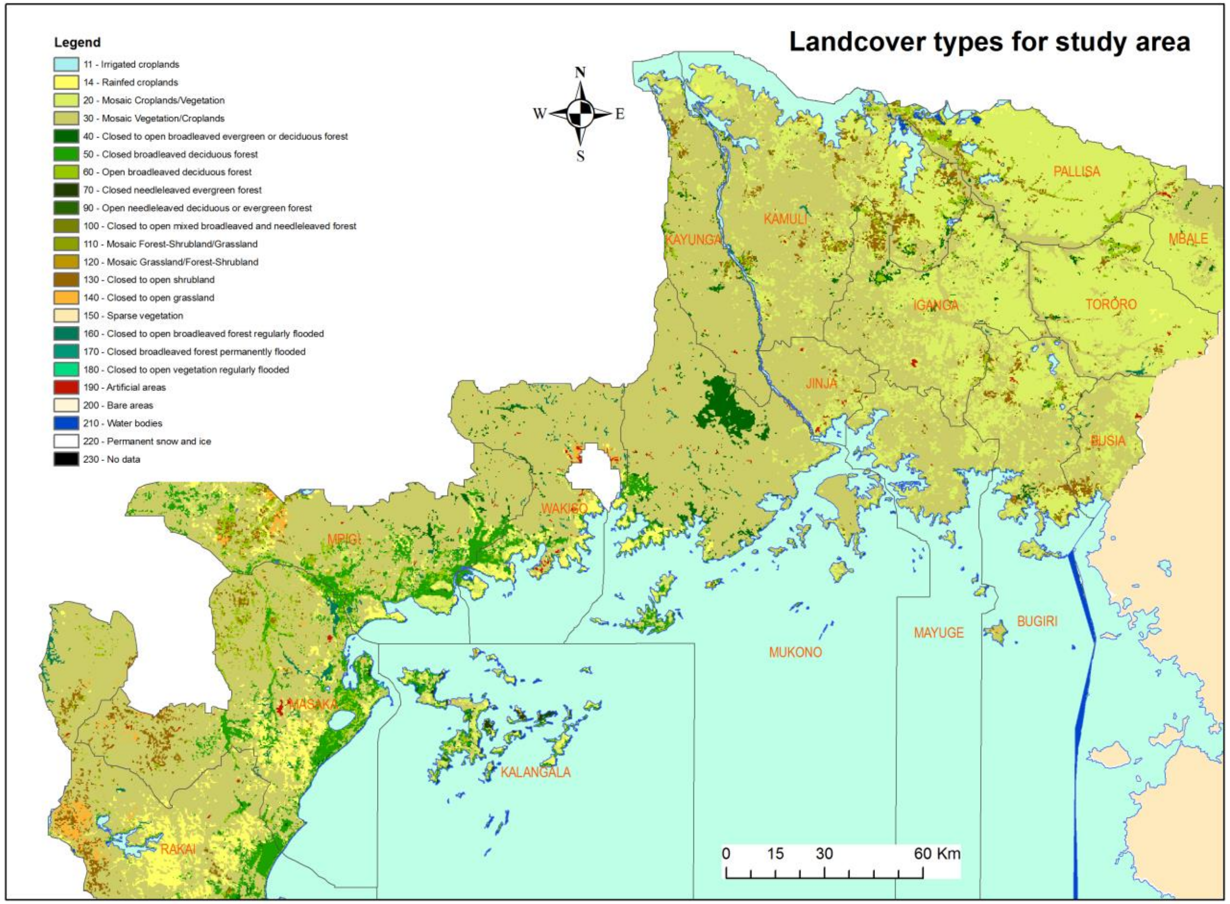


Figure 39 Landcover types (2009) for study area

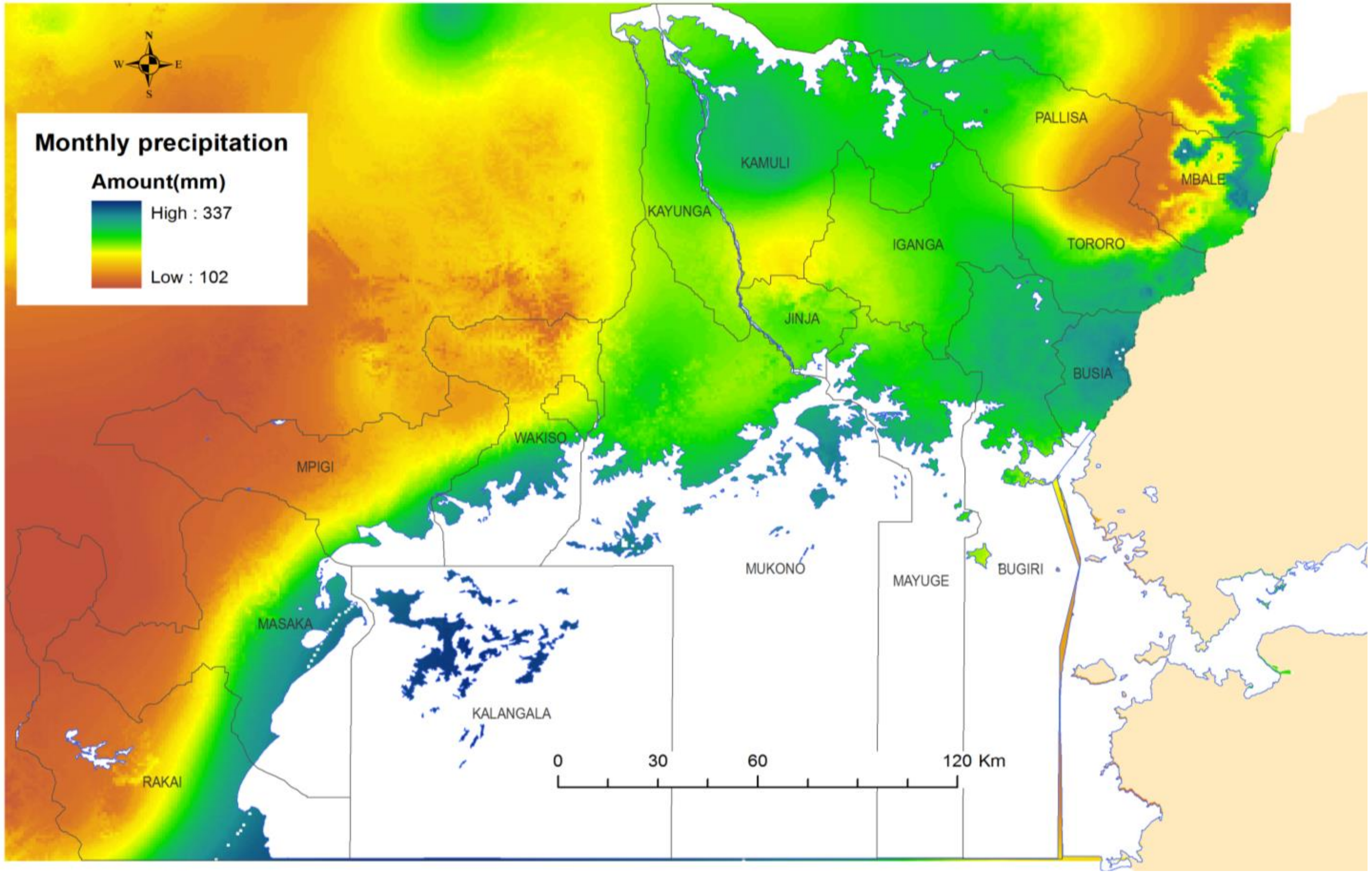


Figure 40 Monthly average precipitation for study area

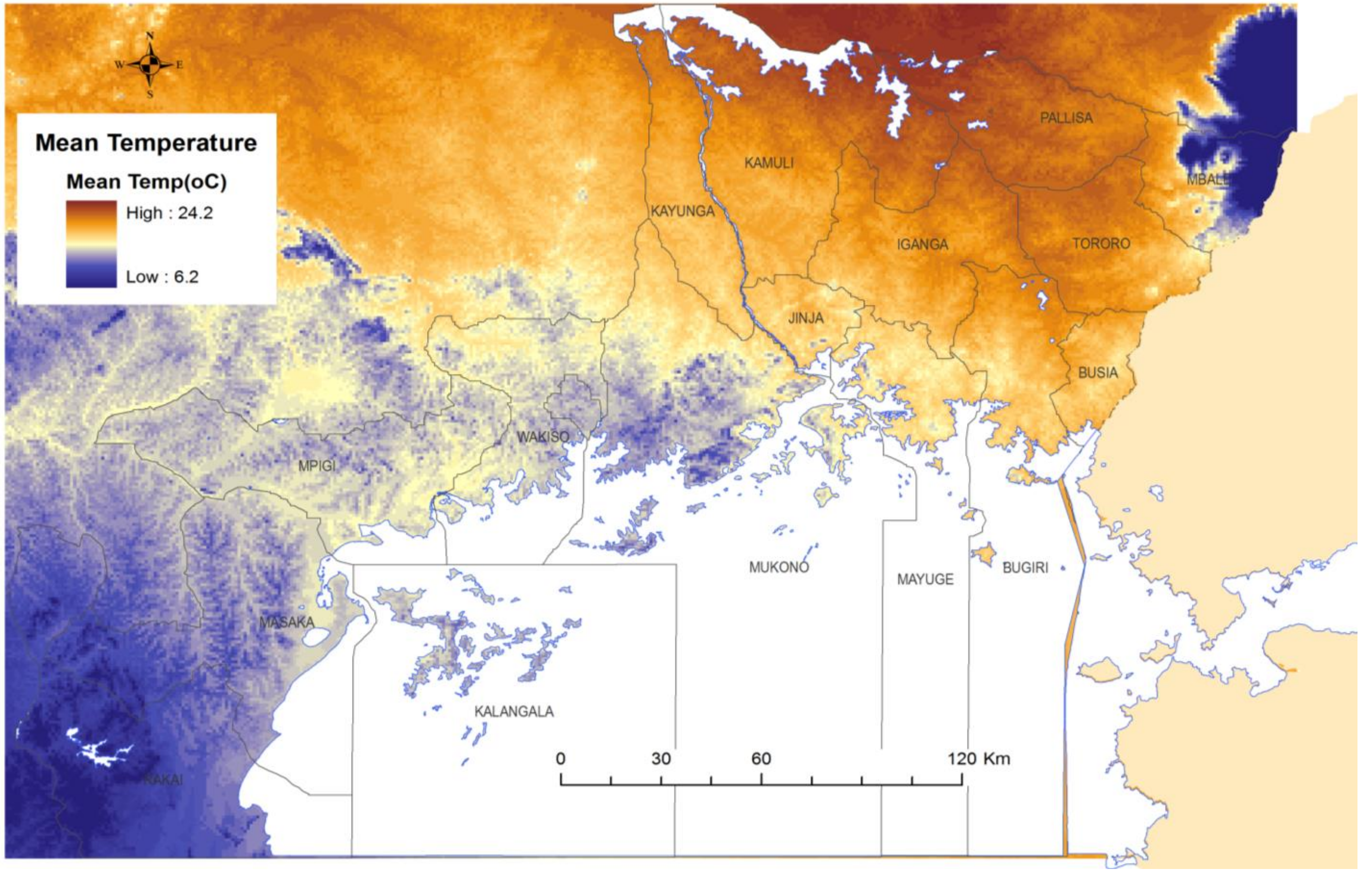


Figure 41 Mean Temperature for study area

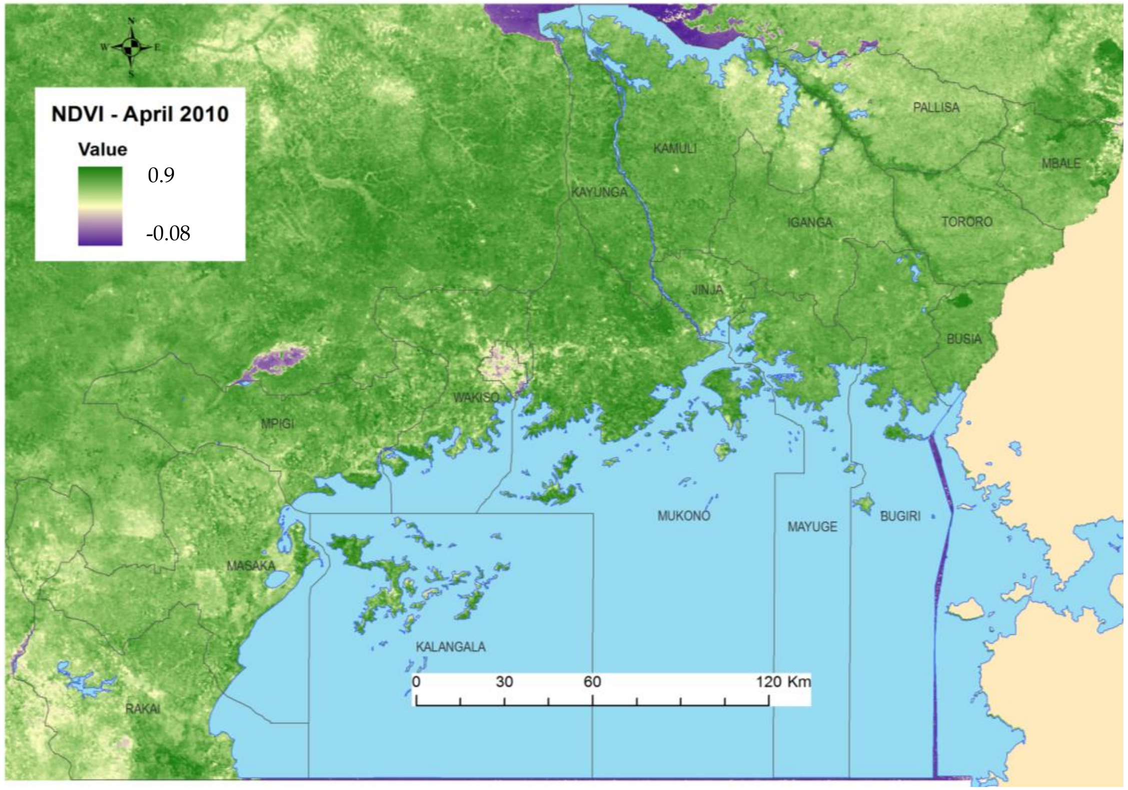


Figure 42 Normalised difference vegetation index for study area

- Negative values of NDVI (values approaching -1) correspond to water.
- Values close to zero (-0.1 to 0.1) generally correspond to barren areas of rock, or sand.
- Low, positive values represent shrub and grassland (approximately 0.2 to 0.4),
- High values indicate temperate and tropical rainforests (values approaching 1)

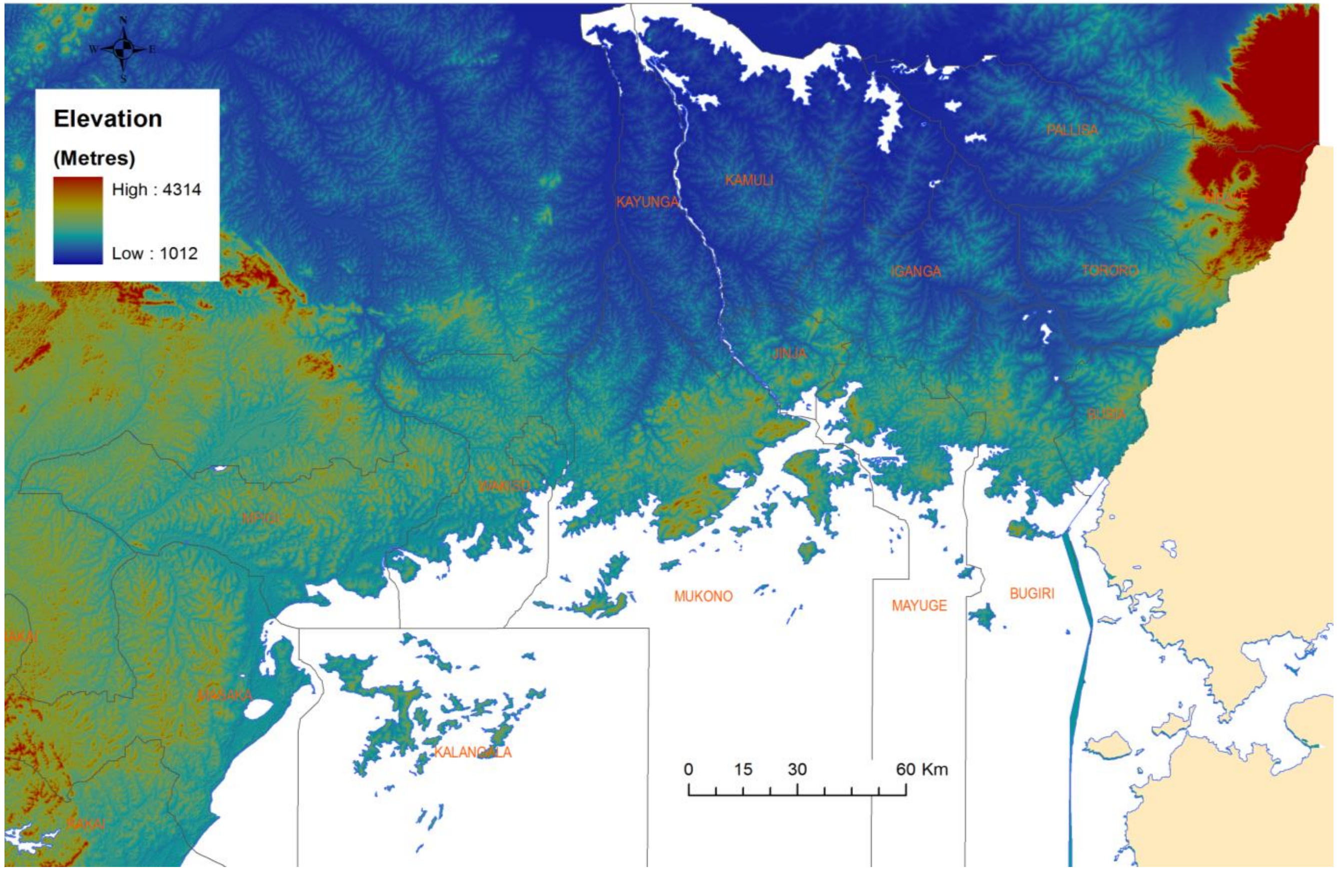


Figure 43 Elevation for study area

Figure: 42 represents the NDVI across the study area. NDVI is a measure of vegetation cover or biomass production from multispectral satellite sensor imagery, derived from the National Oceanic and Atmospheric Administration (NOAA) satellites Global Inventory Monitoring and Modelling Studies group (GIMMS) data. Raster values of NDVI for vegetated land generally range from about 0.1 to 0.7, with values greater than 0.5 indicating dense vegetation (USGS FEWS NET Data Portal). All data are provided in GeoTIFF format with embedded colour tables. Coordinate System Description: Geographic; Units: DD (decimal degrees), Spheroid: WGS84 and Pixel size: 250 x250m.

The temperature (Figure: 41) and precipitation (Figure: 40) datasets used in the model were obtained as interpolated raster data and processed at a fine spatial resolution of 30 arc-secs (~1 km). The processed data were supplied by the *WorldClim - Global Climate Data* facility (Hijmans et al. 2005).

Elevation data (Figure: 43) used in the model were obtained from the Shuttle Radar Topography Mission (SRTM). The SRTM is an international project spearheaded by the National Geospatial-Intelligence Agency (NGA), NASA, the Italian Space Agency (ASI) and the German Aerospace Center (USGS, 2004). The elevation data were obtained and aggregated at a spatial scale of 1 km within the study area.

4.4.3 Data analysis

Tsetse survey count data were transformed to a binary variable representing tsetse fly presence or absence [0, 1]. Presence of tsetse flies was represented by a "1" while absence of tsetse flies was represented by a "0". Preliminary visualisation of the geographical distribution of tsetse presence was carried out using the ArcMap10 GIS software.

Table 16 GlobCover codes and description

	User code	User label	Description	Area occupied (Km^2)
1	LC011	Irrigated cropland	Post-flooding or irrigated croplands (or aquatic)	< 1
2	LC014	Rainfed cropland	Rainfed croplands	1,035
3	LC020	Cropland	Mosaic cropland (50-70%) / vegetation (grassland/shrubland/forest) (20-50%)	6,294
4	LC030	Savannah	Mosaic vegetation (grassland/shrubland/forest) (50-70%) / cropland (20-50%)	16,023
5	LC040	Tree plantations	Closed to open (>15%) broadleaved evergreen or semi-deciduous forest (>5m)	460
6	LC050	Woody vegetation	Closed (>40%) broadleaved deciduous forest (>5m)	1,101
7	LC060	Woodland	Open (15-40%) broadleaved deciduous forest/woodland (>5m)	751
8	LC070	Closed montane forest	Closed (>40%) needle-leaved evergreen forest (>5m)	28
9	LC090	Open montane forest	Open (15-40%) needle-leaved deciduous or evergreen forest (>5m)	18
10	LC100	Mixed montane forest	Closed to open (>15%) mixed broadleaved and needle-leaved forest (>5m)	< 1
12	LC110	Forest	Mosaic forest or shrubland (50-70%) / grassland (20-50%)	63
13	LC120	Grassland	Mosaic grassland (50-70%) / forest or shrubland (20-50%)	16
14	LC130	Shrubland	Closed to open (>15%) (broadleaved or needle-leaved, evergreen or deciduous) shrubland (<5m)	686
15	LC140	Herbaceous vegetation	Closed to open (>15%) herbaceous vegetation (grassland, savannas or lichens/mosses)	136
16	LC150	Sparse vegetation	Sparse (<15%) vegetation	< 1
17	LC160	Swamp forest	Closed to open (>15%) broadleaved forest regularly flooded (semi-permanently or temporarily) - Fresh or brackish water	236
18	LC170	Shrubs on flooded land	Closed (>40%) broadleaved forest or shrubland permanently flooded - Saline or brackish water	8
19	LC180	Closed grassland	Closed to open (>15%) grassland or woody vegetation on regularly flooded or waterlogged soil - Fresh, brackish or saline water	7
20	LC190	Built-up area	Artificial surfaces and associated areas (Urban areas >50%)	46
21	LC200	Bare areas	Bare areas	16
22	LC210	Riverine/lacustrine vegetation.	Water bodies	24,040
		Total area		40,000

4.4.3.1 Interpreting the covariates

Exploratory analysis was performed as a means to check for outliers, aspects of homogeneity, normality and collinearity / multi-collinearity within the predictor variables. Exploratory analysis, univariate and the multivariate analysis were performed using the R Statistical software package (R Development Core Team 2006).

4.4.3.1.1 Outliers in data

Outliers in data were investigated using boxplots and dot charts. Such plots are able to show the direction of data skewness. They are used to show data distribution at a glance. Through such enquiry it is possible to know which covariates are normally distributed, which have more lower / upper outliers etc. In all, boxplots give you a good idea of what the data are like in terms of distribution before its application in the model.

4.4.3.1.2 Aspects of collinearity

The relationship among different covariates was measured using scatterplots. Scatterplots are a graphical way of representing relationships between two variables usually by points. Scatterplots hold the ability to determine the strength and direction of the relationship between variables under consideration. Such strength and direction of linear association is normally computed using a correlation coefficient (Pearson-r). Depending on the nature of the relationship, a correlation can be positive, negative or simply zero. Scatterplots were applied in estimating the relationship between the outcome variable (Tsetse presence / abundance) and the covariates (temperature, rainfall, NDVI, land cover and elevation).

4.4.3.1.3 Normality

An examination of the distributions for normality was conducted on all raw covariates and also their residuals using histograms.

Interpretation of histograms follows the shape of the resultant histogram shape.

4.4.3.2 Univariate regression analysis

All covariates were entered into a univariate logistic regression analysis to assess their influence on tsetse presence (outcome variable). Land-cover variables applied in the analysis were obtained through the creation of buffers of 1 km (catchment) around each entomological tsetse survey point. Within each buffer, area percentages of the different land cover types were computed and used as the set of land cover predictor variables. In total, 22 variables were entered into a univariate analysis. Subsequently, all covariates with *p*-value greater than 0.05 were dropped and excluded from further analysis. P-values of less than 0.05 are often reported as being statistically significant and interpreted as being small enough to justify rejection of the null hypothesis. Significant variables in the univariate analysis (Table: 17) were further subjected to cluster correlation and a correlation matrix generated to detect any aspects of multi-collinearity. Where this occurred, it was decided to remove the least significant covariates. Multi-collinearity is considered a problem if any pair-wise correlation is greater than $r=0.5$ (Dielman, 1991). And if R^2 values are close to 1.0, multicollinearity is present and this will result into the inflation of standard errors of the coefficients.

4.4.3.3 Multivariate regression analysis

The multivariate approach followed was a forward-step-wise approach to enable exclusion of next level non-responsive variables from the model, resulting in a final multivariate logistic regression model. Covariates were added one after the other cumulatively and each had to maintain its significance to be retained. Estimated full model coefficients were compared with those obtained at the univariate analysis stage to ascertain the consistency of final covariates in influencing the outcome variable.

The Logistic regression model is presented in (Equation: 1). The probability (p) of tsetse presence (Y=0 or 1) at a given location based on a predictor variable is determined by the formula;

$$P_x = \frac{e^{b_0+b_1x_1+b_2x_2}}{1+e^{b_0+b_1x_1+b_2x_2}}$$

Equation 1

Where;

P_x = Probability of tsetse presence, scaled from 0 to 1

b_0 = Intercept

b_i = Coefficients of predictors variable

x_i = Measured values for predictor variables

For a multivariable model such as this, the slopes (coefficients) represent the change in the logit (of tsetse presence) corresponding to a change of one unit in the independent variable.

A residual variogram was constructed to assess the presence of spatial autocorrelation in the model residuals. Autologistic regression was applied to reduce the residual spatial autocorrelation (Besag, 1974; Carsten, 2007; Huffer and Wu, 1998; Augustin et al. 1996).

Autologistic regression (AR) is an approach introduced in 1996 (Augustin et al. 1996) and is used to address the problem of spatial autocorrelation (SAC) in species distribution data (Carsten, 2007). Autologistic regression is widely used in ecology studies (Betts et al. 2009). The process involves the introduction of a new explanatory variable (*autocovariate*) which is used in the correction of the spatial autocorrelation effect. The value of the *autocovariate* depends on the values of the response variable in the defined neighbourhood (Carsten, 2007). The autocovariate is calculated only once from the observed data and not changed during the model estimation process (Carsten, 2007; Augustin et al. 1996). Autologistic regression involving several covariates is determined using the formula;

$$\ln \frac{\pi_i}{1-\pi_i} = \alpha + \beta s(y_i) + \sum_k \gamma_k x_{ki} + \varepsilon_i,$$

Equation 2

Where;

$s(y_i)$ is the *autocovariate* and is a function that summarises the y-values in the neighbourhood of ***i***. It is calculated from the observed data only once and used throughout.

x_{ki} are the values for ***k*** different environmental variables used to explain the occurrence of ***y*** in ***i***.

α is the model intercept

β_i is the coefficient that relates to the observed occurrence ***y*** at a given location

ε_i is the error in distribution

The strength of the spatial autocorrelation was quantified by the Global Morans's I index as extending up to a distance of 20km (Carsten, 2007). Thus, a spatial range of 20km was used as the distance over which spatial autocorrelation was detectable within the data. All analyses were performed using the software R, version: Rstudio2011, with additional packages; geoR, gstat, MASS and spdep.

An evaluation of alternative techniques to critically specify relationships between the dependent variable and driving factors can improve performance of resultant models. Yu-Pin Lin et al.(2011), used and compared the performance of logistic, autologistic and artificial neural network (ANN) while quantifying the relationships between land uses and their drivers. The application of autologistic and (ANN) proved very useful in the identification of the essential drivers. Autologistic regression models have been used in various research works including; poverty analysis (Petrucci et al 2004), modelling species (Wintle and Bardos, 2006), distribution of vegetation (Fang-liang et al. 2003), distribution of plant species in Florida (Wu and Huffer, 1996), plant diseases (Besag, 1974) and incidence of foot rot (Besag, 1977).

Receiver operating characteristic (ROC) curves were generated to evaluate model performance based on suggested cut-off points. Sensitivity and specificity are the links through which the predictive ability of the model is assessed. The two parameters are estimated by classifying every observation that has a predicted probability of occurence (p>0.5) as positive and those with probabilities (p<0.5) as negative (Dohoo et al. 2010). Lowering the probability threshold will increase sensitivity while increasing the probability threshold will lower sensitivity, but increase specificity (Metz C.E, 1978). Precisely, sensitivity refers to the ability of the model to predict tsetse presence where regressional probabilities are greater than 0.5 while specificity refers to the ability for the model to predict tsetse absence where probabilities are less than 0.5. The area under the ROC curve (AUC) was calculated to assess the predictive ability of the model (Dohoo et al. 2010). The area under the ROC curve was used to provide an assessment of how well the model can perform in the classification of the study area into tsetse presence / absence zones.

Spatial prediction was carried out using the final multivariate model parameters, along with spatially continuous covariate datasets, to enable visualisation of predicted probability of occurrence for both the sampled and unsampled locations. The unsampled locations were represented on a regular grid and the predictions were used to produce continuous surface maps. The probabilities were derived from the regression equation in which the linear predictor is transformed using the logit function into a value between 0 and 1. Values close to '0' represent a high probability of tsetse absence while '1' represents a high probability of tsetse presence.

4.5 Results

4.5.1 Binary map for Tsetse

A map of tsetse presence and absence based on the tsetse sampling points is presented in Figure: 44. From this map, it is evident that the data point locations of the outcome variable (tsetse presence) are fairly evenly distributed throughout the study area, but with heterogeneity in tsetse presence. Most of the tsetse flies are found in the northern and eastern parts of the Victoria basin including all islands. For the southern and western parts of the basin there is limited evidence of tsetse presence.

4.5.2 Univariate Logistic Regression results

As indicated in Table: 17, 44% of the land cover variables had a statistically significant association with tsetse presence (p-value<0.05). Covariates; cropland, forest, riverine vegetation, woody vegetation, NDVI, elevation, temperature and rainfall were all positively significant ($p<0.05$, OR>1) while rainfed cropland, savannah vegetation, herbaceous vegetation and built-up area demonstrated negative significance ($p<0.05$, OR<1) with tsetse presence. Covariates; tree plantations, woodland, montane forest, shrubland, grassland, swampy forest, closed grassland, bare areas and shrubs on flooded land were not significantly associated with the outcome ($p>0.05$). Temperature variable was most significantly associated with the outcome variable ($p < 0.05$, OR=2.611) while woody vegetation returned the least significant association.

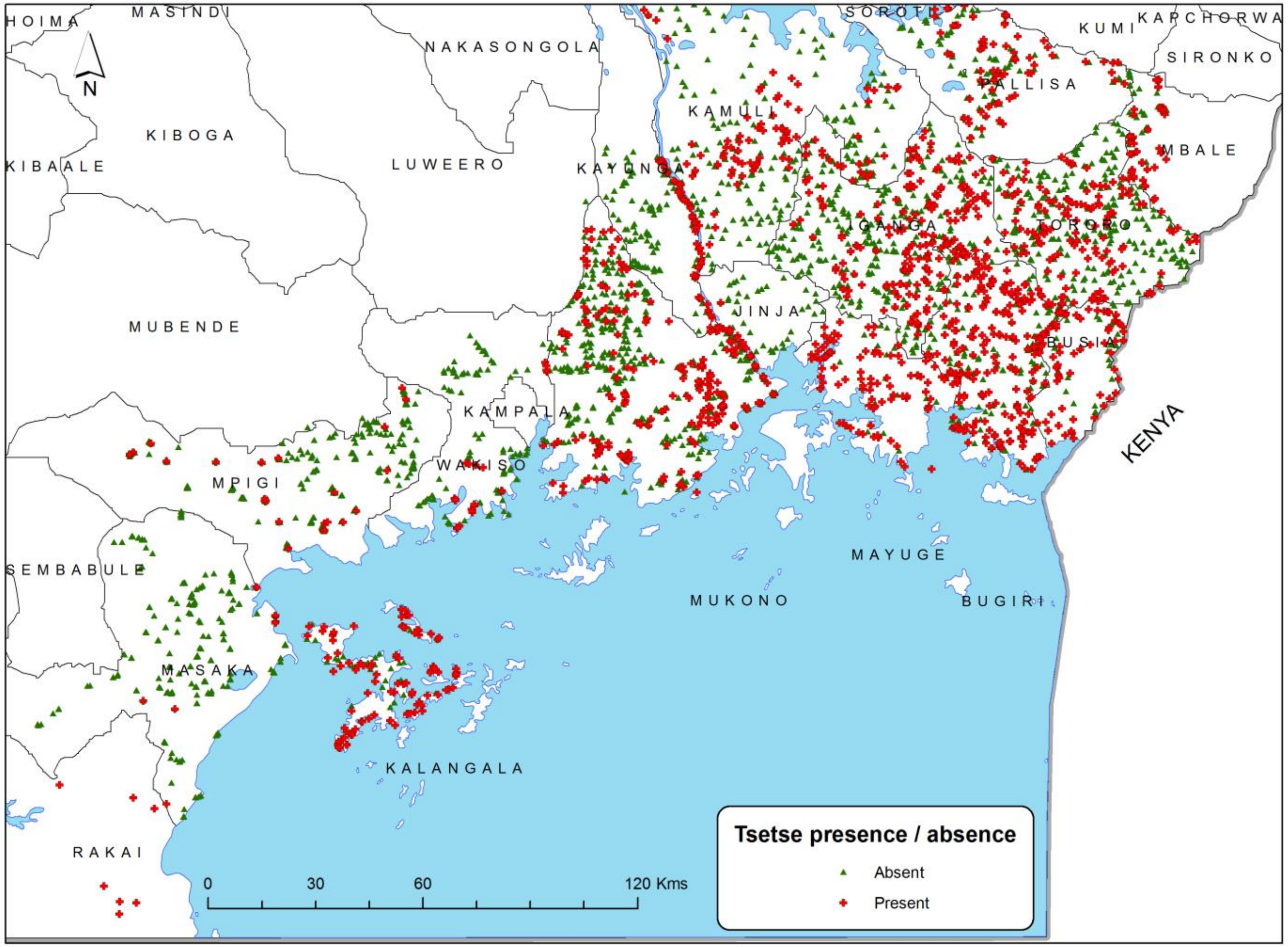


Figure 44: Binary map for tsetse presence /absence illustrating the extensive nature of the field survey.

The NDVI variable was defined for three months (April, May and June) and each month was found to be highly correlated with one another (approx. r = 85%). This necessitated the removal of the May and June NDVI variables as they were well represented by the NDVI for April. This was to avoid collinearity problems in modelling.

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The univariate analysis shows that the amount of rainfall received in the study area has a statistically significant association with the presence of tsetse flies ($p <0.05$, OR = 1.025). By inference, greater rainfall implies a higher probability of tsetse presence.

Table 17 Univariate regressional results for all covariates

Covariate	Estimate	Pr(>|z|)	Odds Ratio	CI (2.5%)	CI (97.5%)
Rainfed cropland	- 0.051	<0.05	0.951	0.930	0.969
Cropland	0.003	<0.05	1.002	1.000	1.005
Savannah	- 0.008	<0.05	0.992	0.990	0.994
Tree plantations	0.002	0.791	1.002	0.984	1.020
Woody vegetation	- 0.049	<0.05	0.100	0.929	0.974
Woodland	0.001	0.860	1.001	0.982	1.020
Closed montane forest	0.009	0.782	1.009	0.947	1.087
Open montane forest	-0.107	0.088	0.898	0.788	1.021
Forest	0.197	<0.05	1.217	1.110	1.340
Grassland	0.084	0.522	1.088	0.842	1.430
Shrubland	- 0.001	0.832	0.998	0.987	1.009
Herbaceous vegetation	- 0.143	<0.05	0.866	0.765	9.616
Swamp forest	- 0.026	0.205	0.974	0.933	1.010
Shrubs on flooded land	0.385	0.137	1.469	1.022	2.929
Closed grassland	- 0.078	0.203	0.925	0.743	9.893
Built-up area	- 0.095	<0.05	0.909	0.824	9.814
Bare areas	0.261	0.121	1.297	0.963	1.868
Riverine vegetation.	0.015	<0.05	1.014	1.005	1.023
NDVI	0.016	<0.05	1.016	1.004	1.008
Temperature	0.960	<0.05	2.611	2.162	3.156
Rainfall	0.024	<0.05	1.025	1.007	1.023
Elevation	0.006	<0.05	1.006	1.021	1.027

From the data used, monthly rainfall amounts varied between 34 mm and 339 mm for the different parts of the study area. Like for NDVI, the rainfall variables used in the model were defined for three months (April, May and June). The correlation coefficients for rainfall indicated that the three months were highly correlated (*r* > 80%). Consequently, April rainfall was selected for use in further analysis.

These univariate regression results further indicate that all temperature variables applied in the model were significantly associated with tsetse presence (*p* <0.05, OR=2.611). This implies that the probability of tsetse presence increases with increasing temperature. Note also that, all the temperature variables had a high correlation of close to one *(r* = 98%*)*. Consequently, a decision was made to consider only one temperature variable in the model to avoid multicollinearity. Specifically, to match with other environmental surrogates, mean temperature for April was considered for use in the model as it was the most significant.

In the area under study, altitude was very weakly associated with tsetse presence (P<0.05, OR=1.006). The lowest altitude in the study area is 1034 m while the highest point is 1412 m above sea level and the average height is 1135 m above sea level. These heights fall within the acceptable tsetse fly height ranges and thus rendering the covariate less essential in determining fly presence.

4.5.3 Multivariate logistic regression results

Only significant variables registered at univariate level were considered for the multivariate logistic regression. The multivariate regression model was constructed using a forward-stepwise approach and only eight covariates retained their significance. The significant covariates were; rainfall, elevation, temperature, rainfed cropland, cropland, savannah vegetation, forest, and riverine vegetation. The multivariate logistic model parameter estimates are given in Table: 18.

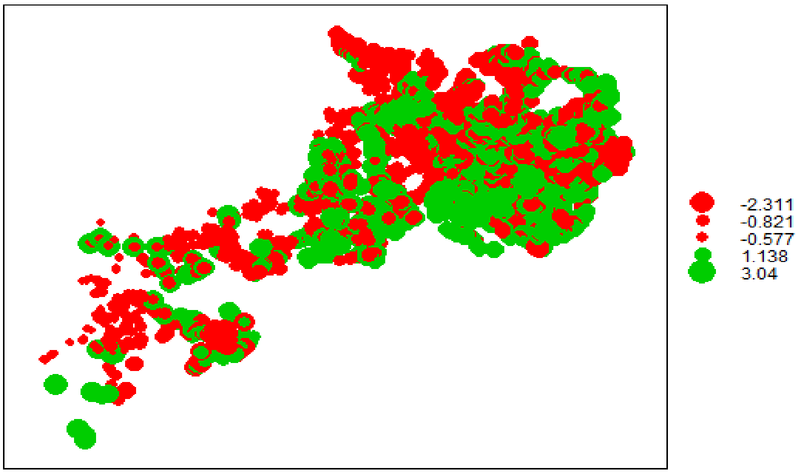
The presence of tsetse flies was negatively correlated with two variables i.e. rainfed cropland and savannah (Table: 18). This implies that for 5% decrease in odds ratio there is a 1% decrease in the proportion of rainfed cropland, while for 1% reduction in odds ratio there is a 1% decrease in proportion of savannah vegetation (Table: 18). The remainder of the model covariates demonstrated a positive correlation with tsetse presence. However, covariates like cropland, riverine vegetation, elevation and rainfall presented very small positive association and with brief confidence intervals.

Table 18 Multivariate regression: variables used in logistic model fitting and their estimated parameters

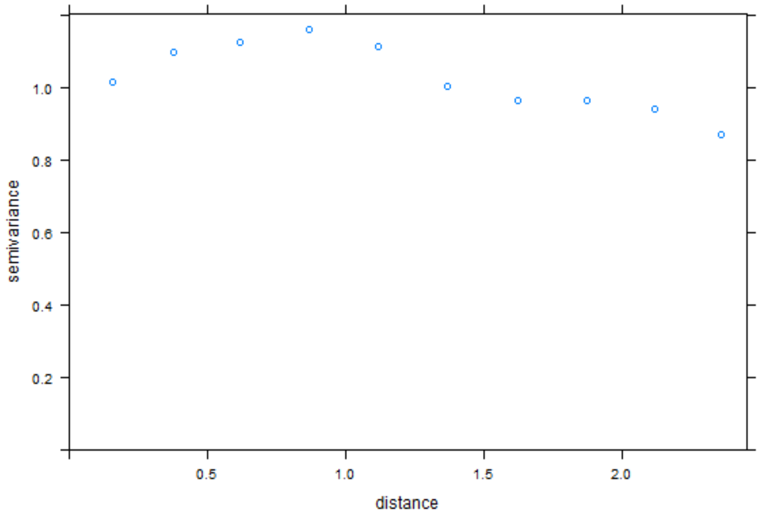
		Estimate	SE	P-Value	Odds Ratio	C.I (95%)
	Intercept	<0.001	3.084	P<0.05	<0.001	<0.001 – 0.001
1	Rainfed cropland	- 0.052	0.010	P<0.05	0.95	0.929 – 0.967
2	Cropland	0.003	0.001	P<0.05	1.00	1.001 – 1.005
3	Savannah	- 0.007	0.001	P<0.05	0.99	0.991 – 0.995
4	Forest	0.254	0.042	P<0.05	1.29	1.190 – 1.403
5	Riverine vegetation	0.007	0.004	0.0501	1.01	1.000 – 1.014
6	Temperature	0.967	0.092	P<0.05	2.63	2.200 – 3.15
7	Elevation	0.006	0.001	P<0.05	1.01	1.004 – 1.008
8	Rainfall	0.020	0.001	P<0.05	1.02	1.017 – 1.023
AIC = 4925.7 , DF = 4579						

To check for the existence of spatial autocorrelation within the residuals from the multivariate logistic model, a residual analysis involving mapping of residuals and construction of a spatial variogram was undertaken. The map of residuals (Figure 45a) and the variogram (Figure 45b) revealed the existence of some spatial autocorrelation within the data. Presence of residual spatial autocorrelation means that the model is not fully accounting for the variability in the data (Dohoo et al. 2010). And if autocorrelation is not accounted for then the assumptions of regression are violated. There is likely to be underestimation of e.g standard errors –SE (Carsten, 2007).

Since non-spatial models cannot account for the autocorrelation effect, there is need to apply a spatial model like Autologistic Regression (Volker et al. 2006). The Autologistic Regression is a method that accounts for detected aspects of residual spatial autocorrelation in the model.



(a)-Bubble plot: map of residuals from logistic regression



(b)-Residual variogram of residuals from logistic regression

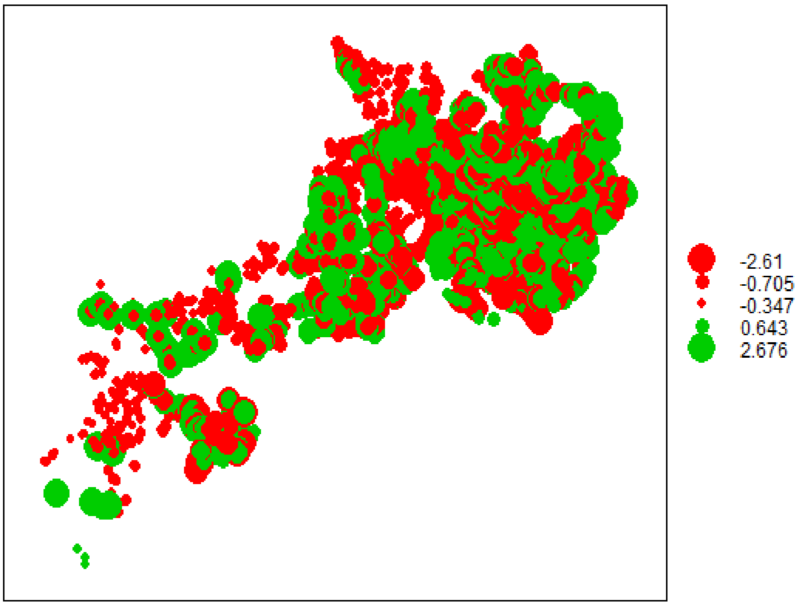
Figure 45 (a-b) Spatial auto correlation in residuals from logistic regression

Autologistic regression was applied based on the eight significant variables obtained from the multivariate logistic model together with the computed autocovariate. The resultant statistics are given in Table: 19 and the new residual variogram is shown in Figure: 39b. The residual variograms for the two models were compared. The autologistic regression model reduced the spatial autocorrelation in the residuals compared to the multivariate logistic model. The Autocovariate was identified as highly significant ($P<0.05$, OR=765.09)

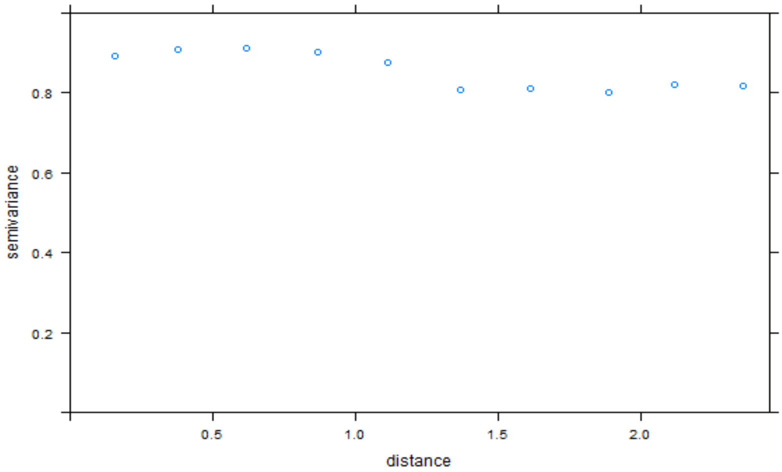
Table 19 Autologistic regression model statistics

Covariate	Estimate	SE	P_value	OR	C.I (2.5%)
Autocovariate	2.316	0.273	$p< 0.05$	765.09	451 - 1316
Forest	0.100	0.047	$p< 0.05$	1.105	1.010 – 1.214
Riverine vegetation	0.008	0.004	$p< 0.05$	1.008	0.999 – 1.016
Savannah vegetation	- 0.007	0.001	$p< 0.05$	0.993	0.991 – 0.996
Elevation	- 0.003	0.001	$p< 0.05$	0.997	0.995 – 0.999
Cropland	- 0.002	0.001	0.118	0.998	0.995 – 1.001
Rainfed crop	- 0.011	0.011	0.284	0.989	0.966 – 1.008
Rainfall	- 0.001	0.002	0.445	0.999	0.995 – 1.002
Temperature	- 0.018	0.110	0.871	0.982	0.790 – 1.219

In the autologistic model, only two variables i.e, forests ($p<0.05$, OR=1.105) and riverine vegetation ($p<0.05$, OR=1.008) were found to be positively correlated with tsetse presence and absence. Savannah vegetation and elevation were negatively correlated. Thus, three landcover classes were considered to be important determinants of tsetse presence / absence in the study area. Rainfed cropland, cropland, temperature and rainfall failed to retain their significant association with tsetse presence ($p>0.05$) after accounting for spatial autocorrelation. Variogram analysis of the Pearson's residuals (Figure: 46b) indicated less spatial autocorrelation than for the variogram for the logistic regression (Figure: 45b).



(a)-Bubble plot: map of residuals from autologistic regression



(b)-Residual variogram of residuals from autologistic regression

Figure 46 Spatial autocorrelation in the residuals from autologistic regression

Model evaluation was conducted to establish how well the model fits the data. The area under the curve (AUC) was computed as 72.7%. The maximum AUC is 100%, attained only if the model has perfect predictive ability. A value of 72.7% indicates adequate predictive ability. The sensitivity and specificity of the model in predicting presence of tsetse was plotted against a range of threshold values (i.e. the probability threshold at which a location would be classified as having tsetse presence (Figure: 47).

The crossing point for both sensitivity and specificity curves marked a suitable threshold for classification of tsetse zones. The plot of sensitivity and false positive (1-specificity) against expected probabilities (Figure: 47) indicates a probability cut-off point at 0.28, leading to a sensitivity and specificity of 53%. This is the point where both specificity and specificity are maximised when predicting the probability of tsetse presence (Metz, 1978).

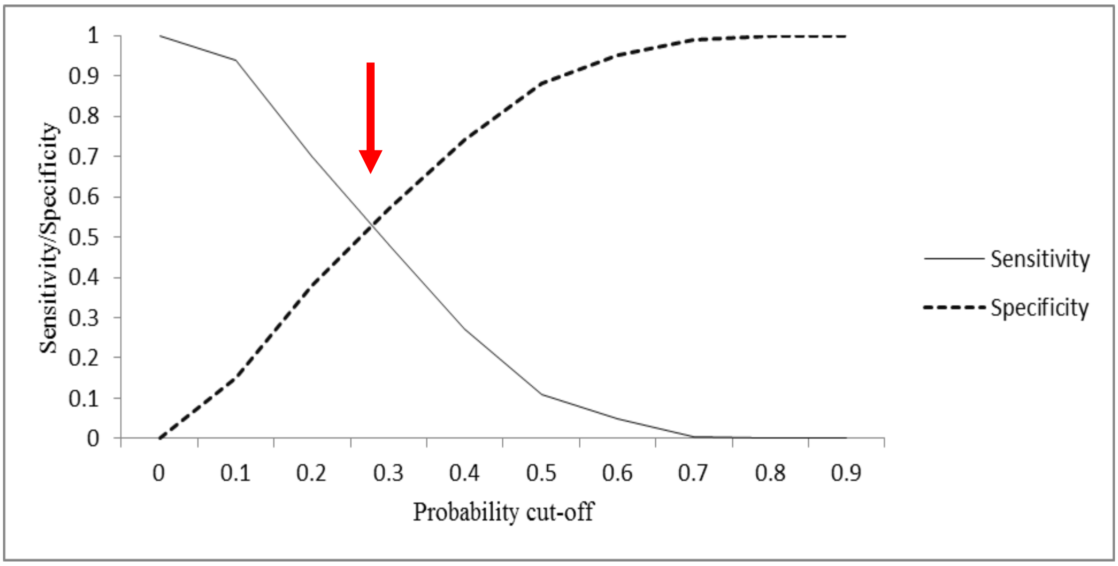


Figure 47, Use of two-graph Receiver operating characteristic (ROC) curves

At a probability cutoff of 0.5, the sensitivity is 10% while specificity is 90% (Figure: 47). This implies that at this Cutoff approximately 90% of all the true positive cases (tsetse presence) will be missed. As the threshold increases, the sensitivity decreases and the specificity increases. For tsetse estimation purposes, the optimal probability threshold for classifying tsetse presence was taken to be 0.28. At that point the threshold for both sensitivity and specificity was approximately 53%. Therefore, the probability of tsetse presence was estimated with accuracies ranging from 28% - 100%.

The predicted *G. f. fuscipes* distribution across the study area, taking different cut-off points is illustrated in Figures: 48(a-b) and 49(a-b). In these figures, it is clear that with a lower cut-off of, for instance, 20%, massive areas are classified as having tsetse flies (over 75% of the study area). The selected optimal threshold of 28%, suggested that tsetse flies occupy approximately 50% of the study area.

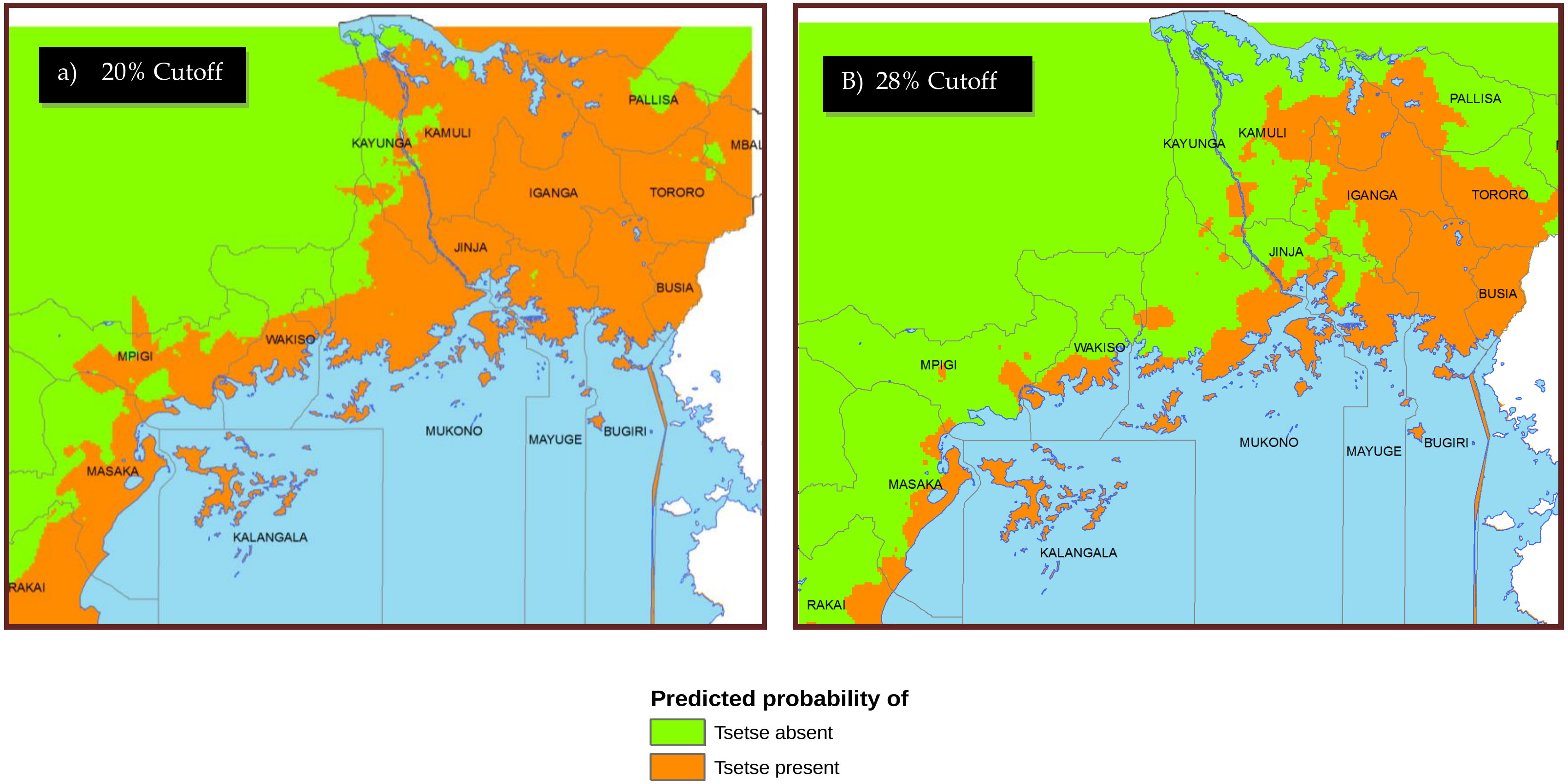


Figure 48: Spatial effect of probability cut-offs for tsetse estimate

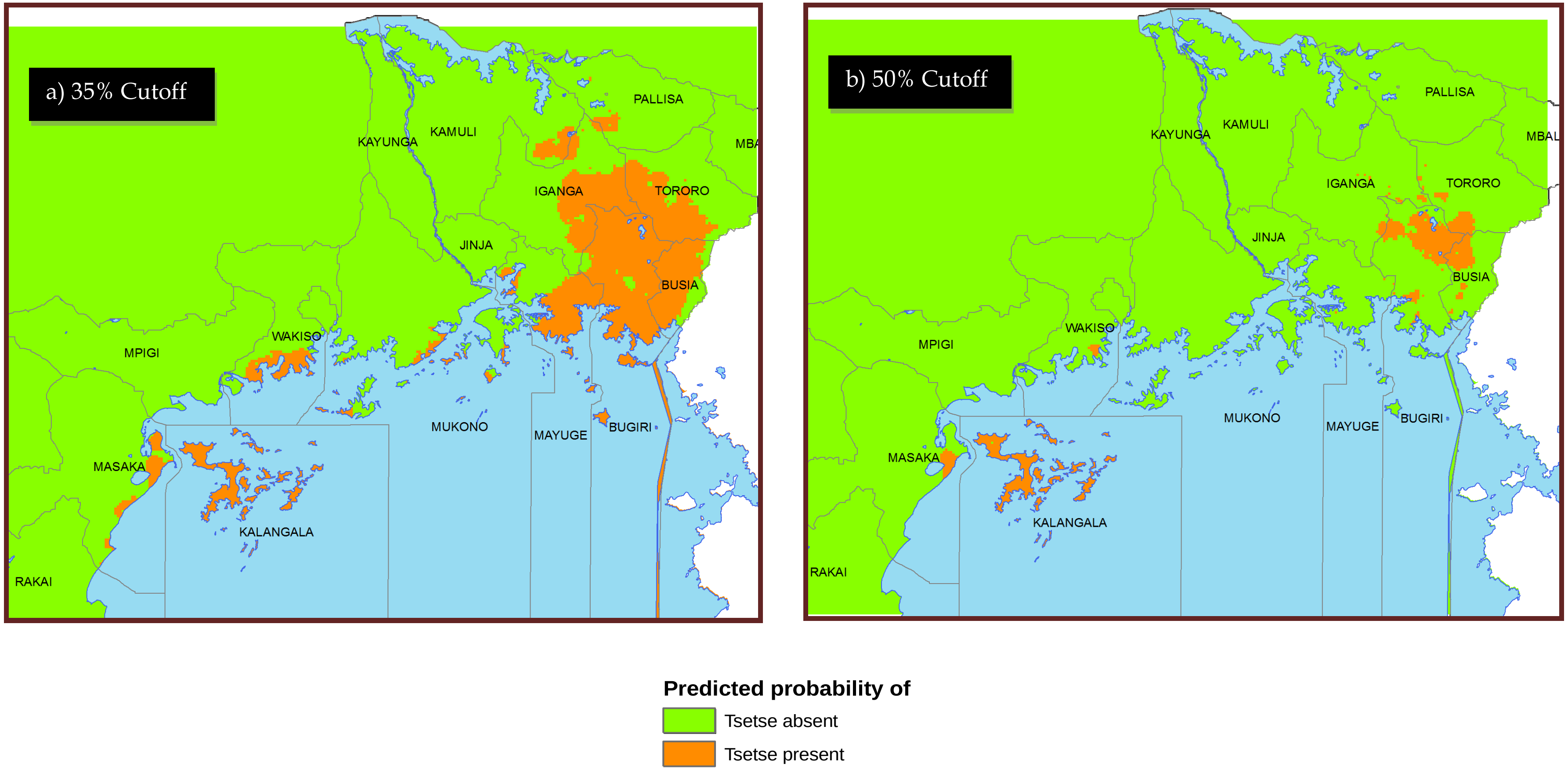


Figure 49: Spatial effect of probability cut-offs for tsetse prediction

The Pearson **X^2** test parameter and Deviance parameter were evaluated as measures of goodness-of-fit. These measures proved statistically non-significant (Pearson X^2 = 4654, p=0.196 (i.e p>0.05) and Deviance = 4890). These results indicate that the model fits the data appropriately and, therefore, could be used to predict probabilities of tsetse presence across the study area.

Spatial prediction was performed based on applying the fitted regression model to the covariates. Figure: 50, shows the predicted probability of tsetse presence across the study area, based on the multivariate logistic regression model (non-spatial model), while, Figure: 51, shows the predicted probability of tsetse presence across the study area, based on the autologistic regression model (spatial model). The two models identify areas of scaled potential tsetse fly risk with estimated probabilities of tsetse presence ranging from 0 to 1.

The outcome reflects the presence of a clear tsetse infestation corridor in the Eastern part of the study area. High probability of tsetse occurrence (predicted probability of occurrence > 75%) was predicted in the eastern sections of the study area close to the Kenya-Uganda border (Bugiri, Busia, Tororo Kaliro, Kamuli and Pallisa districts) as well as on islands located in Lake Victoria. Low probability of tsetse occurrence (below 20%) was predicted in the western and north-western parts of the Lake Victoria basin.

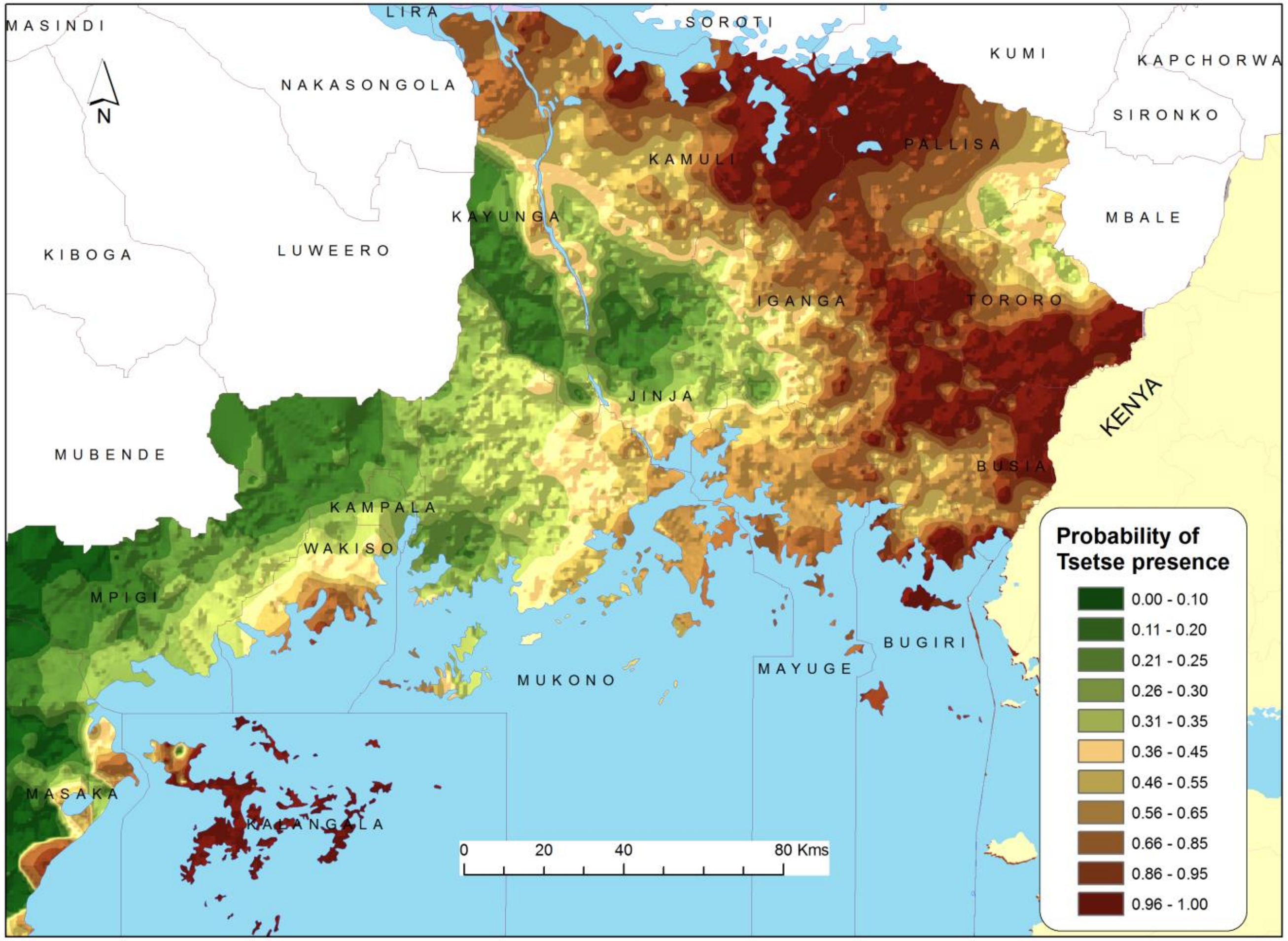


Figure 50 A prediction of probabilities for *G. f. fuscipes* presence in study area based on Logistic regression

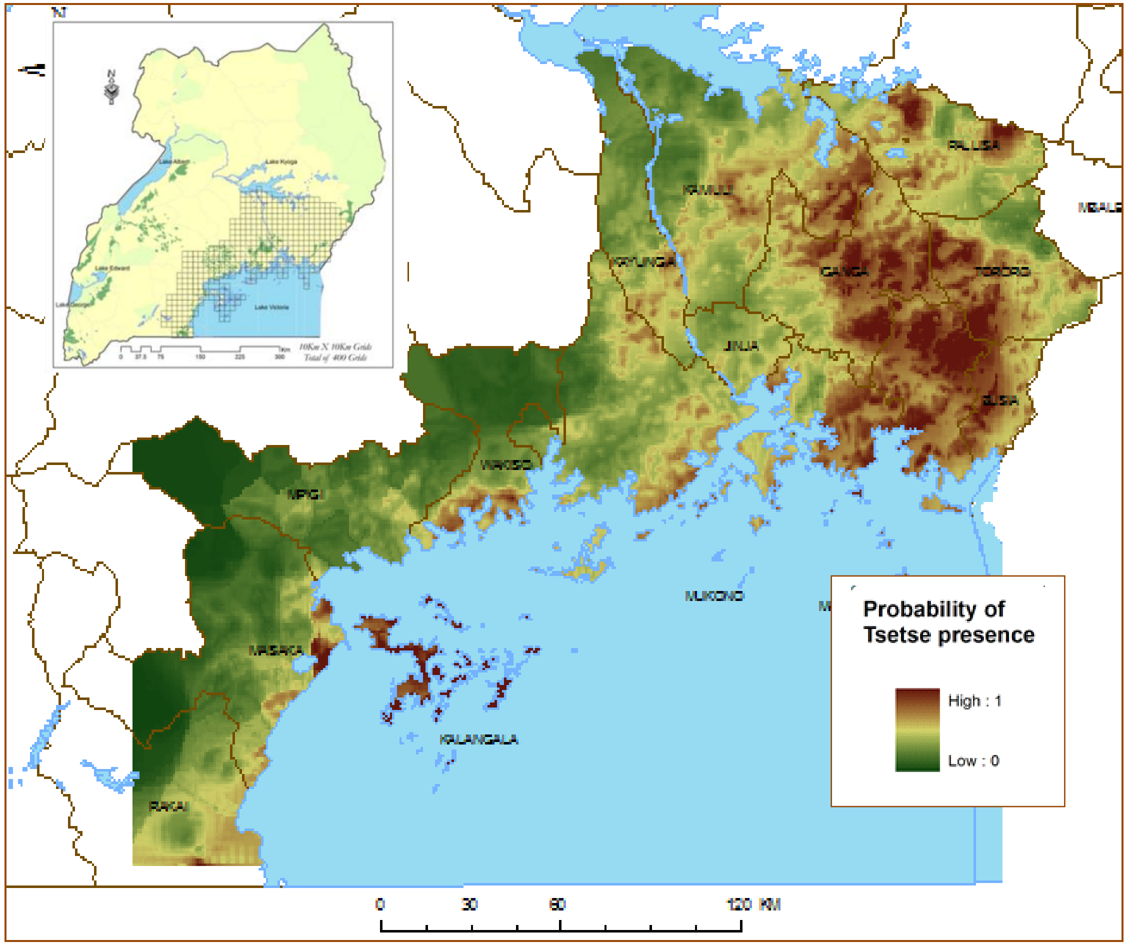


Figure 51 A prediction of probabilities for *G. f. fuscipes* presence in study area based on Autologistic regression

4.6 Discussion

The primary objective of the study was to develop a predictive model that can reliably inform decision-makers about the spatial distribution of *G. f. fuscipes* in the target area of Uganda, based on entomological survey results and a set of environmental covariates. The research was intended to provide high precision, up-to-date, sub-national tsetse data (maps) to guide control interventions. The strength of the results presented in this study is derived from the fine spatial resolution, multi-purpose satellite sensor-based data and the comprehensive tsetse field data applied in both the logistic and autologistic regression models. As complementary to some of the published work on tsetse vector modelling, where some modellers used tsetse point data extracted from previous tsetse distribution maps, here the primary tsetse data were entirely field-based tsetse catch data, acquired in 2010. The tsetse presence and absence data (dependent variable) represent one of the most comprehensive tsetse datasets collected over such a large area and are fully geo-referenced.

At the univariate investigation stage, tsetse presence was found to be significantly associated (positively) with eight variables (.i.e. cropland, woody vegetation, forest, riverine vegetation, NDVI, elevation, temperature and rainfall ($P<0.05$, OR>1). While Rainfed cropland, savannah vegetation and herbaceous vegetation demonstrated a negative association ($p<0.05$, OR<1). For disturbed habitats symbolized by croplands and savannah vegetation, these results make intuitive sense since tsetse flies usually avoid disturbed habitats (Leak, 1999). Additionally, the tsetse sub-species under study (*G. f. fuscipes*) is generally identified as a riverine species and much linked to existence of forested water sheds.

The multivariate logistic regression model established that the presence of tsetse was positively associated with temperature, elevation, rainfall and proportion of forest cover, riverine vegetation and cropland. Whilst savannah vegetation and rainfed cropland had a negative correlation, with the presence of tsetse flies. Tsetse flies are a class of insects that are very sensitive to environmental changes and ecological instability. This implies that tsetse flies are found in ecologically suitable habitats which have the necessary temperature, humidity and vegetation cover (Leak, 1999). *G. f. fuscipes,* as a riverine species of the *palpalis* group, thrives in zones with high humidity and is highly adaptive.

During multivariate analysis, temperature emerged as the most influential variable in determining tsetse presence ($p<0.05$, OR=2.63). Remarkably, tsetse flies thrive in areas with mean annual temperatures of 19-30°C (Terblanche 2008). Temperatures below 19°C slow down tsetse activity and general physiology (Terblanche 2008), while extreme low temperatures increase fly mortality (Moore et al 2010). Tsetse are severely affected by high temperature conditions and once exposed to a temperature of more than 36°C tsetse will have a survival capacity of close to zero (Torr and Hargrove 1999). From the training data, the lowest temperature for the study area was recorded as 13.5°C, the mean temperature was 27°C and the maximum temperature was 29.7°C. Temperature variation was by about 4°C at most sites across the region. These temperature extents have specific consequences on fly availability in the study area as they affect tsetse fly activity and general physiology. This effect was expressed as a large positive correlation in the non-spatial regression model ($p<0.05$, OR=2.63).

During multivariate analysis, elevation returned a weak positive association with tsetse presence ($p<0.05$, OR=1.01). Perceivably, elevation has an influence on the micro-climatic conditions of any area. However, the entire study area has limited height variation (1034 to 1412 m asl) and the model , thus, illustrates the lack of an altitudinal control on tsetse presence within this specific study area with an odds ratio close to 1.

The multivariate model revealed a small positive association between tsetse presence and rainfall ($p<0.05$, OR=1.02). There is an understanding that rainfall received in any given area always replicates environmental and ecological conditions that influence vector existence. For instance, high rainfall is responsible for high humidity, average temperatures and strong vegetation cover, conditions which are concomitant with desired habitats for tsetse presence. The entire study area had monthly total rainfall ranging from 34 to 339 mm which was evenly distributed with no markedly dry areas anywhere within the study area. This condition suffices to explain why rainfall returned a small association with tsetse presence. Thus, the whole study area is generally suitable for tsetse presence based on the rainfall distribution at the time.

The non-spatial model established an influential association of forests cover in determining tsetse presence ($p<0.05$, OR=1.29). *G. f. fuscipes* is a well-known sub-species of the palpalis group which are regarded as riverine species. Therefore the lowly known role of forests in determining tsetse presence is demonstrated by the results of the non-spatial logistic regression.

The logistic model distinguishes cropland as an important variable but less influential in determining tsetse presence ($p<0.05$, OR=1.00). This situation could be linked to its characteristic of being a humanised landscape. There is a tendency for tsetse flies to uniquely avoid such environments. But in circumstances of wide habitat degradation *G. f. fuscipes* takes advantage of the remnant tree cover (garden thickets) as refuge. Thus, in the current setting, it is not astonishing to catch tsetse flies in cultivated lands (cropland).

In the event of accounting for the spatial auto-correlation which had been detected within the non-spatial logistic regression, some covariates completely lost their significance in influencing tsetse presence. Covariates like; temperature, rainfall and cropland lost their significance as they all had p-values greater than 0.05. The use of spatial Autologistic regression enabled the detection of key environmental variables that are highly influential in positively determining tsetse presence and these were; forests and riverine vegetation. Savannah vegetation ($p<0.05$, OR=0.993) and elevation ($p<0.05$, OR=0.997) managed to retain their weak negative association with tsetse presence. Tsetse (*G. f. fuscipes)* thrives in environmental conditions where the vegetation is not too dense such as to enable them fly easily and to be able to spot the feeding host readily. Above all, *G. f. fuscipes* is ecologically considered as a riverine species commonly found in zones of high humidity offered by the interaction between forest vegetation and water bodies. Thus, this finding comes in defence of such existing entomological proclamations.

Autologistic regression established the absence of a significant association between tsetse presence and variables like cropland, temperature and rainfall. Overall, this could be attributed to the level of homogeneity of some of these environmental variables across the entire study area.

The introduction of an Autocovariate component into the ordinary logistic regression model significantly increased the overall accuracy. The ordinary logistic regression was inadequate because spatial correlations remained after the regression of tsetse presence with selected covariates.

Fitting the Autologistic regression model permits us to estimate using the odds of tsetse presence if a neighbouring quadrat is tsetse infested relative to if neither neighbour is infested. This model gave estimates of the increased odds of tsetse presence with increased forest cover and riverine vegetation. The spatial dependence parameters for temperature, rainfall, cropland and elevation appeared less important after accounting for the effect of both forest cover and riverine vegetation.

It is important to recognise the persistent presence of spatial auto-correlation even though of reduced magnitude. This scenario seems to suggest that there are critical variables that have not been introduced into the model. These need to be investigated further.

4.7 Conclusion

Several tsetse sub-species have long been associated with the Lake Victoria basin. The new location-specific entomological data gathered for this study provide further evidence of the extensive distribution of tsetse in the area. Using the entomological survey data, a tsetse distribution map for the lake basin was constructed as already illustrated. Unfortunately, the mapped information is point based and only valid for the sampled points. The major outcome of this chapter has been the transformation of point-based tsetse catch data into a continuous surface tsetse data using spatial modelling tools (Autologistic regression). This regression model enabled the identification of important environmental variables that are influential in determining tsetse presence across the study area. Notably, the final model identified forests and riverine vegetation (positive) and savannah vegetation (negative) as the key covariates associated with tsetse presence in the study area. This seems to suggest that the variability in elevation, climate and other environmental variables across the study area is too small to condition the tsetse fly distribution relative to forest and riverine vegetation. Knowledge of the influential factors and availability of detailed sub-national tsetse distribution maps offers a platform for making meaningful decisions when planning tsetse control interventions.

This specific study provides information exclusively on probability of tsetse presence across the study area, with no indication of tsetse abundance which is certainly of importance for decision makers when designing and quantifying targeting interventions. The following chapter (Chapter 5) sets out to answer this essential concern.

CHAPTER 5: PREDICTING ABUNDANCE OF TSETSE FLIES

5.1 Introduction

Vector control programmes often make use of insect abundance and distribution data to plan interventions. Insect abundance refers to the measured population of insects in a unit area at a given timescale. It is commonly determined using detailed field survey data. Such data especially for large areas are often not readily available. In many cases programme managers depend on estimates of insect abundance obtained through application of probability-based sampling techniques using fine field survey count data from small areas to plan their activities. Fine resolution data is key and explicit in ensuring delivery of reliable estimates of insect abundance within an area (Speight et al. 1999). However, a major issue that has to be explicitly addressed when estimating insect abundance is the problem of false negatives (e.g. zero tsetse catch results in areas where tsetse do exist) (Sileshi 2007). Species do not always occupy all areas that are suitable for them, or are not always found, even when they occur there, due to low abundance and chance (Rogers et al. 1996). Spatial heterogeneity in abundance within "suitable" areas impacts on disease transmission.

The abundance of a target species is a fundamental ecological parameter and a critical consideration when making management and control decisions (Sileshi 2007). Location specific insect count data collected by entomologists during control and monitoring programmes acts as an informer on approximate levels of insect abundance in a given area. Sileshi (2007) asserts that; "there are many kinds and levels of decisions that need to be made based on insect abundance". For instance monitoring the performance of tsetse (*Glossina spp.*) control programmes depends largely on periodically measuring insect abundance. Such status usually determines the next steps.

Discussions on tsetse distribution (Chapter 4) indicated that at a finer scale, the presence of tsetse flies in an area is highly influenced by the presence of forest and riverine vegetation. Other variables like rainfall, temperature, elevation and other land cover types were considered important but less influential in determining tsetse fly presence.

Tsetse species abundance is a component of biodiversity and refers to how common or rare a particular tsetse species or sub-species is in a defined location or community (Hubbell, 2001). Insect abundance is regulated by abiotic factors (such as temperature, moisture of breeding habitat and humidity) and biotic factors (parasites, predators and pathogens) and their interaction. These factors uniquely determine the spatial patterns of insect abundance. Among abiotic factors, temperature and humidity stand out as the most important ones constraining abundance and distribution of insects (Matilda et al. 2012). Temperature regulates the ecology of insect communities. Overall, insects are very sensitive to climatic changes (Hay et al 1996).

Abundance of tsetse fly species (*G. Pallidipes and G.m.morsitan*) has been positively correlated with temperature in some studies (Torr et al 1999). Fly physiology and behaviour influences fly abundance and spatial distribution. Thus, that study focused on the interaction of micro-climate and fly reproduction in influencing tsetse abundance.

Taylor (1984) contends that spatial distribution yields characteristic parameters that segregate species. And that these parameters are the population expression of the individual behaviour defined by the ethologist (scientific and objective study of animal behaviour) and observed by the naturalist. Like other species, insects are linked to unique spatial patterns that are influenced by ecological settings. The environment influences the behaviour and physiology of tsetse flies, which then determines their spatial patterns.

Tsetse fly abundance maps have been constructed in some countries at very small scales of commonly 1: 1,000,000. For instance during the period 1979-1980, Cote d'Ivoire with support of FAO/GTZ collected flies from sampled points and produced sub-national tsetse fly abundance maps (Rogers et al. 1996). These have been a resource to the entomology sector in the country. Similar studies leading to mapping of tsetse distribution and abundance have been conducted in East Africa (Wint, 2001), Togo (Rogers at al. 1994), Zimbabwe (Rogers and Williams 1993), Kenya / Tanzania (Rogers and Randolph 1993) and Ghana (Hendrickx et al. 1995). There are no records signifying any previous mapping leading to the production of tsetse abundance maps in Uganda. The current national tsetse data available for Uganda (Wint 2001) is explicitly on presence/absence rather than abundance.

The aim of this investigation was to determine the relationship between several environmental variables and tsetse fly abundance. While many records in literature indicate a great scale on demarcation of zones characterised as having tsetse, less is clear about which zones have no tsetse flies (Rogers et al. 1996). Worse still is that the tsetse fly abundance aspect is never prioritised, despite its importance. Therefore this modelled output will be essential as a decision support towards improved and informed tsetse control and eradication interventions.

5.2 Objectives

The two key objectives of this research were;

(i) To quantify the relationships between tsetse abundance (apparent densities) and external factors (including climatic and environmental variables) in the study area in south-Eastern Uganda and

(ii) To produce a prediction of *G. f. fuscipes* abundance across the study area.

(iii) To compare relationships between predicted fly abundance with the predicted presence

The research is intended to provide fine scale sub-national tsetse abundance maps derived from modelling of recent entomological survey data and remotely sensed satellite sensor data, to support planning of tsetse control and trypanosomiasis elimination in Uganda.

5.3 Methods

5.3.1 Study area

The study area of approximately 40,000Km^2 is maintained composed of largely the Lake Victoria basin in Uganda. A full description and characterisation of this area is provided under section 3.4.1 of chapter 3.

5.3.2 Tsetse fly data

Tsetse count data were obtained from a systematic entomological survey which was conducted in 2010 to ascertain tsetse presence in the Lake Victoria basin of Uganda. Results from field survey work and methodology used are exhaustively covered under chapter 3. Further, a description of tsetse fly data and its packaging for use in regression modelling is presented in section 4.4 of chapter 4. We need to observe here that, unlike under logistic regression where the tsetse parameter extracted and used was presence/absence, for this analysis the parameter used was the actual tsetse counts (numbers). Count data is essential for measurement of species abundance.

5.3.3 Covariate data

Data used in this part of the study is drawn from the same source as in chapter 4 and includes; land cover, temperature, normalised difference vegetation index (NDVI), elevation and precipitation. A full description of the data is made in chapter 4. Summary data specifications are provided in table 20.

5.3.4 Data analysis

5.3.4.1 Regression methods

Two methods are commonly considered for statistical analysis of count data. These are Poisson regression and Negative Binomial regression. The choice of method to be used is normally dictated by the data characteristics. For instance the data could be zero-inflated (excess of zero counts) or could contain aspects of overdispersion (variance is greater than the mean). It is commonly caused by an excess variation between the response (tsetse) counts, clustering in data or existence of outliers in the data (apparent Overdispersion). Once such situations arise, then specific regression approaches are considered. The use of Negative Binomial (NB) or Zero-Inflated Negative Binomial (ZINB) regression becomes paramount. Negative binomial regression can be used under such conditions as first option since it has the ability to account for the overdispersion condition without necessitating the application of a ZINB regression. Particularly, extension of investigation to a ZINB is usually required where the NB model does not adequately fit the data.

Table 20 Predictor variables used in the analyses of tsetse fly distribution and abundance including their observed maximum and minimum values in the training dataset.

Code	Name	Max value	Min value
Meteorological data surrogates	*Rainfall(mm)*		
	Monthly total -April	331	123
	Monthly total –May	339	79
	Monthly total –June	154	21
Meteorological data surrogates	*Temperature (^{0}C)*		
	Max Temp (April)	29.7	25.7
	Mean temp (April)	24.0	20.4
	Min Temp (April)	18.4	15.2
	Max Temp (May)	28.8	26.0
	Mean Temp (May)	23.5	19.8
	Min Temp (May)	18.2	14.6
	Max Temp (June)	28.6	22.0
	Mean Temp (June)	23.2	19.6
	Min Temp (June)	17.8	13.5
Vegetation surrogates	*Normalised difference vegetation index (NDVI)*		
	NDVI-1 (April)	0.90	0.02
	NDVI-2 (May)	0.90	0.01
	NDVI-3 (June)	0.90	0.00
Altitude	*Elevation (m)*	1412	1034
Land cover	*Land cover* (22 Classes) with details listed in Table. 16	n/a	

Poisson regression

Poisson regression is a statistical tool used in the analysis of count data. It derives its name from the "Poisson distribution", which is a mathematical distribution often used to describe count data. Poisson regression is used when the outcome of interest is a count of numbers of events (Pfeiffer et al

2008). Its application is based on several assumptions e.g. observations to be used should be independent while variance should be equal to the mean.

The Poisson regression model expresses the log of the observed count as a linear function of a set of predictors, such that;

$\log_e(Y) = \beta_0 + \beta_1 X_1 + \beta_2 X_2 \ldots$ etc.

and so, $Y = (e^{\beta_0})\ (e^{\beta_1 X_1})\ (e^{\beta_2 X_2})$ .. etc. (*Pfeiffer et al 2008*)

Y=Tsetse apparent density

β_0 = Intercept / estimated constant

β_i= Computed coefficients for each explanatory variable

X_i= Explanatory variable

Equation: 1

The dependent variable is a count of the occurrences of interest and in this case it is the tsetse fly numbers identified in a geographical location. The method enables one to estimate an incident ratio (IR) associated with a given predictor or exposure. This ratio is important as it informs of increment increases in the outcome variable (e.g. tsetse abundance) due to variations in covariates.

To determine the appropriateness of Poisson regression, a histogram was constructed and some crucial parameters computed i.e mean, variance, standard deviations and deviance. The shape of the histogram informs about the possible relevance of applying the Poisson regression on the dataset.

Negative Binomial regression

Negative Binomial regression is considered as a generalization of Poisson regression as it has the same mean structure as Poisson regression but with an extra parameter to account for the over-dispersion. Overdispersion occurs when the conditional variance exceeds the conditional mean and is a common phenomenon among count data and therefore central to the modelling of counts. Failure to address it will lead to underestimation of standard errors causing incorrect assessment of the significance of individual regression parameters.

Negative Binomial regression as a Poisson distribution with extra dispersion was used to predict tsetse abundance across study area with the response variable linked to a linear function of explanatory variables such that;.

$$P(Y = y \mid X_1, X_2, X_3, k) = \frac{\Gamma(y+k)}{\Gamma(k)\Gamma(y+1)}\left(\frac{k}{k+\mu}\right)^k\left(\frac{\mu}{k+\mu}\right)^y \qquad y = 0,1,2,\ldots$$

Γ is the gamma function, Mean(Y) = μ, Variance(Y) = $\mu+(\mu^2/k)$, k is the dispersion parameter, Link Function: log: $g(\mu) = \ln(\mu)$

$$g(\mu) = \log(\mu) = \alpha + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3$$
$$\Rightarrow \quad \mu = e^{\alpha + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3}$$

Equation 2

Preliminary visualisation of the point-based survey data was enabled through the use of ArcMap10 GIS software. Field tsetse survey data were used together with a set of satellite-derived climatic and environmental variables. Exploratory analysis was performed as a means to check for outliers, aspects of homogeneity, normality and collinearity or multi-collinearity within the predictor variables. Exploratory analysis, univariate and multivariate analyses were performed using the R statistical software (R Development Core Team 2006). In this study, the two approaches (i.e Poisson and Negative Binomial) were statistically assessed and the appropriate choice was considered and used in the final prediction of numbers for tsetse fly abundance for the study area.

5.3.4.2 Exploratory analysis

Exploratory data analysis is an important stage in modelling as it guides on model selection. It offers an insight into the training data, enabling the discovery of significant variables, parametric estimates, outliers and general aspects of possible model fitting. The process involved the construction of; (i) Scatterplots (to test for collinearity), (ii) boxplots / dot-plots (to identify outliers), (iii) correlation matrix (to test for multicollinearity) and (iv) histograms / QQ-plots (to test for normality) within the datasets.

5.3.4.3 Univariate analysis

Univariate analysis is a quantitative analysis used in the initial descriptive stages of research data. Such analysis is carried out with the description of a single variable (predictor variable) with respect to the response variable. The influence of each single variable on the response variable is evaluated individually. This was done for each of the two selected regression methods (Poisson and Negative binomial).

All covariates i.e. temperature; land cover, precipitation, NDVI and elevation were assessed individually against the tsetse count data for responsiveness. Landcover parameters applied in the analysis were obtained through the creation of buffers of 1 km (catchment) around each entomological tsetse survey point. Within each buffer, area percentages of the different land cover types were computed and used as the set of land cover predictor variables. As a set condition, all covariates with a p-value greater than 0.05 were excluded from further analysis. Significant variables in the univariate analysis were further subjected to cluster correlation and a correlation matrix generated to detect any aspects of multi-collinearity. Where this occurred, it was decided to remove the least significant covariates from further analysis.

5.3.4.4 Multivariate analysis

Significant predictors delivered from the univariate analysis stage ($p<0.05$) were combined in a multivariate regression analysis to find the best fitting model. The multivariate approach followed was a forward-step-wise approach to enable exclusion of next level non-responsive variables from the model, resulting in a final multivariate regression model. Covariates were added starting with the most significant one after the other cumulatively. Each covariate had to maintain its statistical significance (p-value < 0.05) to be retained. Estimated model coefficients were compared with those obtained at the univariate analysis stage to ascertain the consistency of final covariates in influencing the outcome variable. To check for spatial autocorrelation in the residuals from the final model, a residual variogram was constructed, as described in chapter 4. To address spatial autocorrelation, an autocovariate was computed and introduced into the regression equation of the statistically responsive regression method. The outcome formed the basis for prediction of probabilities for tsetse abundance.

Use of Autocovariate: An Autocovariate is an explanatory variable introduced to the regression model to correct the effect of spatial autocorrelation. The values of the Autocovariate depend on the values of the response variable in the neighbourhood (Dormann, 2007). The autocovariate term accounts for the expectation of sites closer in space to be more similar to one another than sites farther apart. The study made use of 'weights by inverse distance' as the distance–weighting scheme. Therefore, the inclusion of an autocovariate in the model enables the capture, with high certainty, the important covariates influencing tsetse fly abundance within a given area.

The autocovariate term has application in most generalized linear models in form of auto-poisson, auto-negative binomial or autologistic regressions (Dormann and Bivand, 2008).

Assessing model fitting; Fitness of the Poisson and Negative Binomial regression models was assessed through; (i) computation and examination of the deviance as an approximate goodness-of-fit test, (ii) comparison of residual deviance with the X^2 distribution, (iii) examination of the Akaike information criterion (AIC) score and (iv) generating residual plots e.g. a plot of the standardised deviance residuals against the predicted values. The standardised deviance residuals will approximately be normally distributed with equal variance if the model assumptions are satisfied. Further, correlation between observed and predicted values was computed.

Spatial prediction; Spatial prediction was carried out using the final multivariate model parameters for the Negative Binomial regression and auto-Negative Binomial regression.

5.4 Results

Figure 52 shows the observed tsetse density as derived from the entomological field survey data for only *G. f. fuscipes* as the main species of focus. Included in the same figure is the distribution of *G. Pallidipes* also derived from the survey data.

From this map (Figure 52), it is evident that the data point locations of the outcome variable (Tsetse density) are evenly distributed throughout the study area, but with heterogeneity in tsetse abundance. Most of the high densities of tsetse flies are found in the northern and eastern parts of the Victoria basin including Kalangala islands. For the southern and western parts of the basin the density is close to zero completely. Presence of *G.*

Pallidipes is restricted to small patches located to the south-eastern part of the study area (Tororo and Busia districts).

Table 21 lists the important predictor variables with their statistical response values as observed during the univariate analysis based on *Poisson* regression analysis. All covariates were statistically significantly associated with tsetse abundance (p<0.05). The histogram (Figure 53) shows the graphical representation of the dependent variable (tsetse fly count) against frequencies, indicating overdispersion.

Table 21 Poisson regression: univariate regression results

Covariate	Estimate	SE	P-Value	IR	CI (95%)
Rainfed cropland	-0.06	0.01	<0.05	0.94	0.93 – 0.96
Cropland	0.20	0.01	<0.05	1.23	1.20 - 1.26
Savannah	-0.01	<0.01	<0.05	0.99	0.99 – 1.00
Tree plantations	-0.62	0.12	<0.05	0.54	0.42 – 0.67
Woody vegetation	-1.56	0.09	<0.05	0.21	0.18 – 0.25
Woodland	1.43	0.07	<0.05	4.16	3.65 – 4.74
Closed montane forest	1.49	0.09	<0.05	4.43	3.71 – 5.28
Open montane forest	0.87	0.23	<0.05	2.39	1.52 – 3.71
Forest	0.68	0.03	<0.05	2.03	2.01 – 2.33
Grassland	-6.79	1.47	<0.05	0.01	0.01 – 0.02
Shrubland	0.50	0.04	<0.05	1.64	1.50 – 1.79
Herbaceous Vegetation	-4.03	0.33	<0.05	0.02	0.01 – 0.03
Closed grassland	-2.17	0.54	<0.05	0.11	0.03 – 0.28
Built-up area	-3.18	0.60	<0.05	0.04	0.01 – 0.12
Riverine veg.	0.51	0.03	<0.05	1.66	1.58 – 1.75
Elevation	0.24	<0.01	<0.05	1.00	1.00 – 1.01
NDVI	0.38	<0.01	<0.05	1.00	1.00 – 1.01
Temperature	0.80	0.03	<0.05	2.23	2.09 – 2.35
Precipitation	0.02	<0.01	<0.05	1.02	1.02 – 1.03

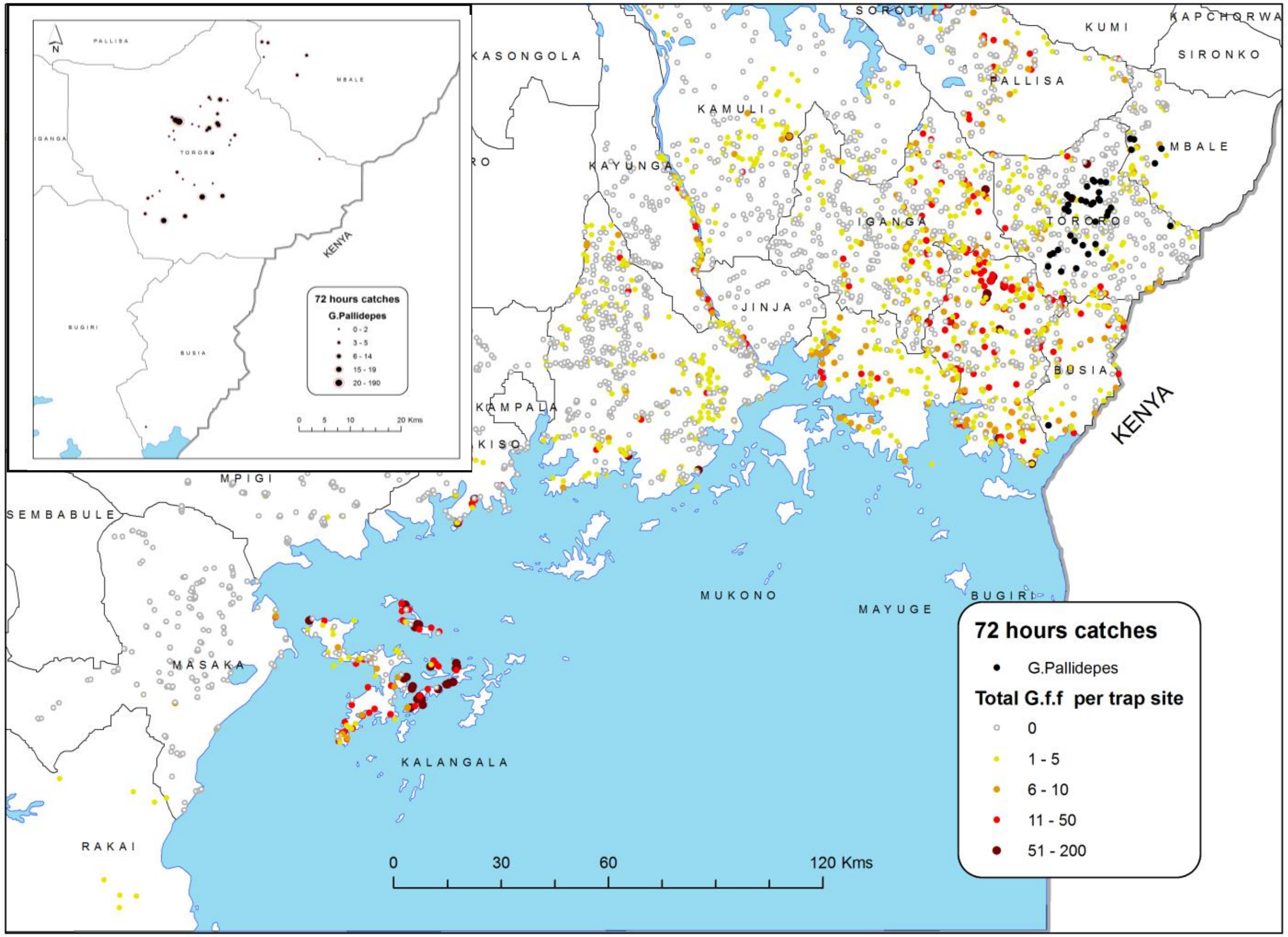


Figure 52 Tsetse apparent densities for *G. f. fuscipes* and distribution of *G. Pallidipes* as mapped from field survey data

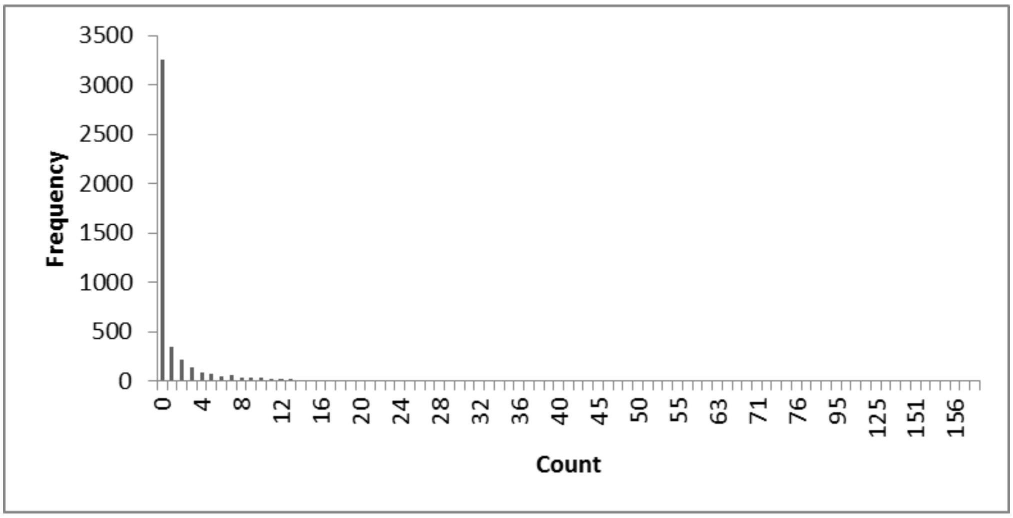


Figure 53 Histogram for the tsetse count data

Tabulated data below shows the computed statistics from the preliminary Poisson regression investigation.

N = **4850**	Mean = **2.65**	Standard deviation = **10.68**
Variance = **114.12**	Skewness = **0.84**	Kurtosis = **-0.1**

Table 22 shows results from the *Negative Binomial regression*, revealing that, at univariate analysis stage only 58% of the land cover variables produced a statistically significant (*p*-value<0.05) correlation. Covariates; cropland, woody vegetation, woodland, closed montane forest, open montane forest, shrubland, shrubs on flooded land, bare areas, riverine vegetation, temperature and rainfall showed a positive correlation with tsetse count (*p*<0.05, IR>1), while savannah vegetation, NDVI and elevation demonstrated a negative correlation (*p*<0.05, IR<1) with tsetse count. Covariates; Rainfed cropland, tree plantations, forests, grassland, closed grassland, herbaceous vegetation, and built-up area were not significantly associated with the outcome (*p*>0.05).

The univariate analysis shows that the amount of rainfall received in a specified area has a statistically significant association with the apparent density of tsetse flies (*p* <0.05, IR = 1.025). By inference, greater rainfall implies a higher tsetse abundance (apparent density). From the data used, monthly rainfall amounts varied between 34 mm and 339 mm for the different parts of the study area.

Table 22 Negative Binomial regression: univariate regressional results

	Covariate	Estimate	SE	Pr(>|z|)	IR
1	Rainfed cropland	0.461	0.275	0.09	1.585
2	Cropland	0.295	0.066	<0.05	1.343
3	Savannah	-0.329	0.055	<0.05	0.719
4	Tree plantations	-0.102	0.489	0.84	0.902
5	Woody vegetation	2.294	0.362	<0.05	9.918
6	Woodland	2.358	0.404	<0.05	10.56
7	Closed montane forest	0.035	1.510	<0.05	4.435
8	Open montane forest	-0.023	3.479	<0.05	2.395
9	Forest	3.279	1.965	0.10	2.654
10	Grassland	-2.080	6.860	0.76	0.124
11	Shrubland	0.749	0.297	<0.05	2.120
12	Herbaceous vegetation	2.806	2.232	0.21	16.54
13	Shrubs on flooded land	0.134	6.273	<0.05	1.370
14	Closed grassland	-1.947	1.109	0.08	0.142
15	Built-up area	-3.003	1.607	0.06	0.049
16	Bare areas	0.055	5.646	<0.05	0.744
17	Riverine	1.559	0.144	<0.05	4.758
18	Elevation	-0.007	0.001	<0.05	0.993
19	NDVI	-0.027	0.004	<0.05	0.973
20	Temperature	0.253	0.069	<0.05	1.287
21	Precipitation	0.025	0.001	<0.05	1.025

The univariate regression results indicated that temperature was significantly associated with tsetse abundance (*p<0.05,* IR=1.287). This implies that, to some extent, tsetse abundance increases with increasing temperature.

In the area under study, altitude was negatively correlated with tsetse abundance (*$p<0.05$,* IR=0.993). The lowest altitude in the study area is 1034 m while the highest point is 1412 m above sea level and the average height is 1135 m above sea level. These heights fall within the acceptable tsetse fly height ranges.

The application of Poisson regression is based on the assumption that the conditional variance equals the conditional mean. According to the data, variance = 114.1 and mean = 2.65. Thus, variance is greater than mean. This implies that the data are over-dispersed and presumably not appropriate for use in a *Poisson regression*. Therefore, the preferred choice for measuring association between environmental variables and tsetse fly abundance was *Negative Binomial* approach.

Deviance is a measure of dispersion and should be as close to 1 as possible. If deviance is significantly greater than 1 then there is over dispersion in the data. However, overdispersion could be solved by adding more variables to the model. Due to over dispersion, the deviance for the multivariate poisson model is 7.9 while that for multivariate negative binomial is 0.6 (table 23), leading to a better estimate of the standard error (SE) under the multivariate negative binomial regression.

Table 23 Criteria for assessing Goodness of fit

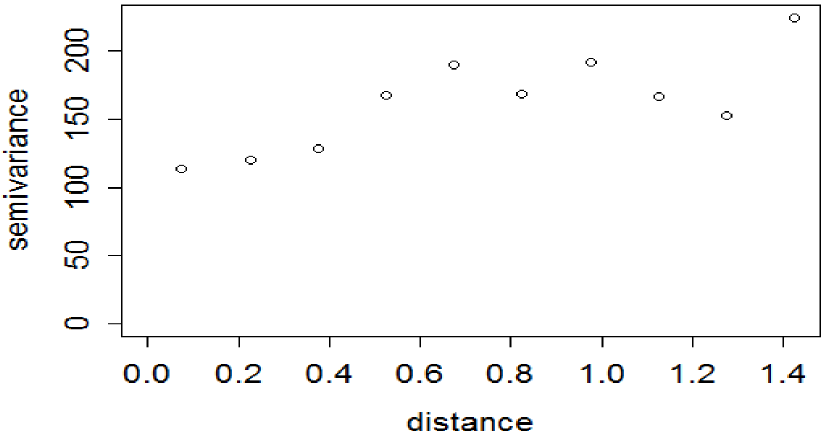
	Poisson regression	*Negative Binomial regression*
Scaled Pearson (X^2)	0	0.117
AIC	40,410	12,544
Deviance	7.9	0.6
Variance	114.1	114.1
Mean	2.65	2.65
Algorithm	No convergence	Model converged

Table: 24, lists the 6 most important predictor variables for *G. f. fuscipes* abundance based on the multivariate negative binomial regression. The variables included in the final multivariate regression model were: riverine vegetation (IR=2.039) temperature (IR=2.7161), precipitation (IR=1.027), shrubland (IR=1.908), cropland (IR=1.162) and savannah (IR = 0.718).

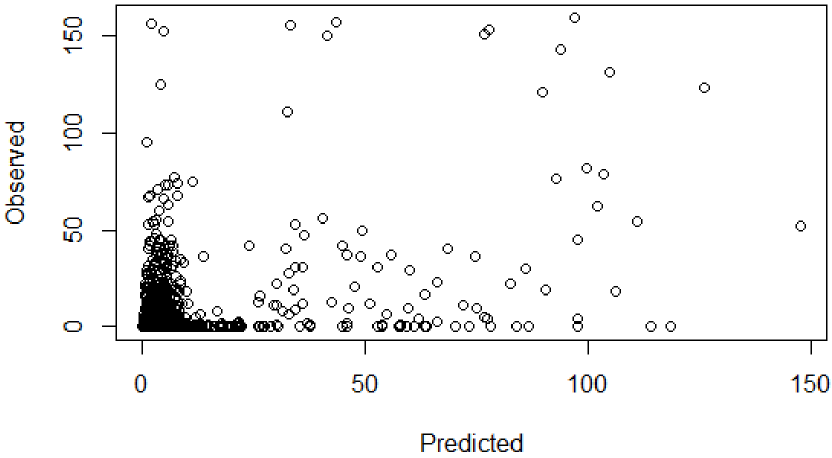
Table 24 Negative Binomial regression: multivariate analysis statistics

	Est.	SE	IR	Pr(>|z|)	CI (95%)
Intercept	-27.707	1.614	< 0.05	< 0.05	0.01 – 0.01
Temperature	1.016	0.070	2.761	< 0.05	2.393 – 3.192
Riverine vegetation	0.713	0.154	2.039	< 0.05	1.513 – 2.813
Shrubland	0.646	0.267	1.908	< 0.05	1.176 – 3.356
Cropland	0.151	0.063	1.162	< 0.05	1.029 – 1.318
Precipitation	0.027	0.002	1.027	< 0.05	1.023 – 1.030
Savannah	-0.331	0.051	0.718	< 0.05	0.649 – 0.796

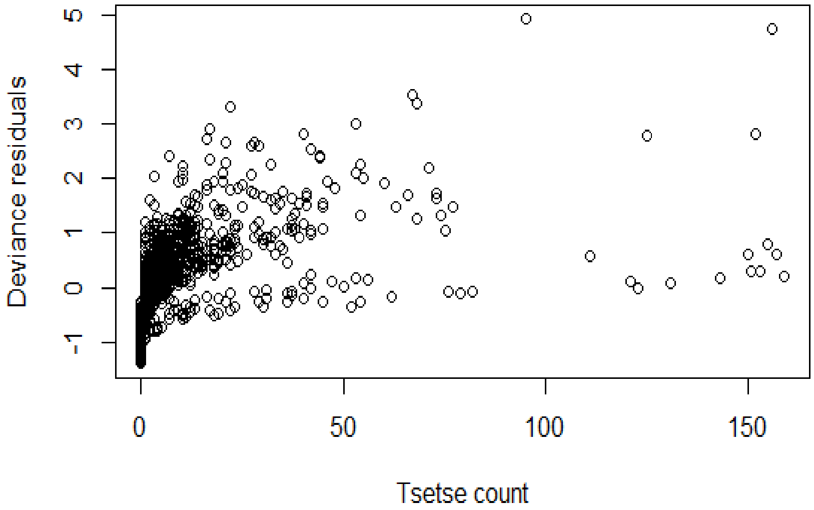
Figures: 54(a-d) illustrate the results from the investigation of the spatial autocorrelation in the residuals from the multivariate negative binomial regression model. They include; (a) a residual variogram (using Pearson residuals), (b) a scatterplot for observed against fitted, (c) deviance residuals and (d) a map of residual values. The variogram (Figure 54 a) reveals the existence of spatial autocorrelation within the data, which should be accounted for in the analysis (e.g. via the inclusion of an autocovariate term).



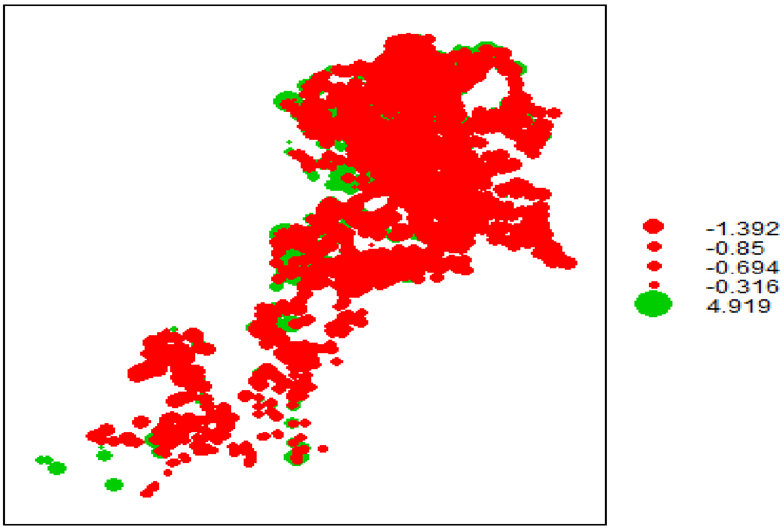
(a)- Residual Variogram (Pearson residuals)



(b)- Scatterplot for observed against fitted



(c)- Deviance residuals



(d)- Residual spatial autocorrelation

Figure 54 (a-d) Spatial autocorrelation for Negative binomial

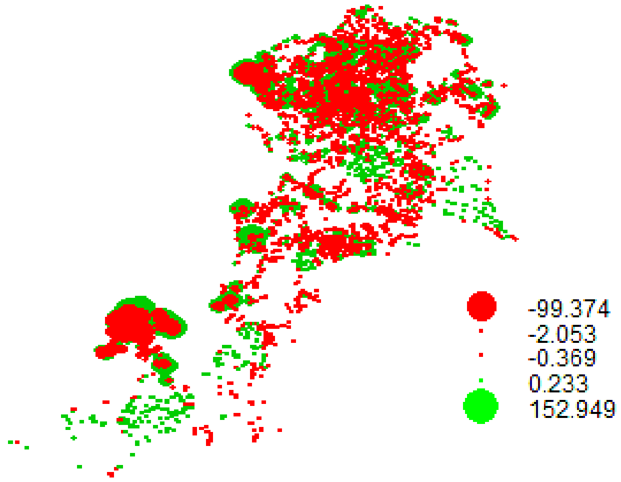
Table 25, shows the statistical results for the predictor variables, in order of importance, based on the Auto-Negative Binomial regression. It is an improvement on the ordinary Negative Binomial regression as it involves the introduction of the *Autocovariate* to address aspects of spatial autocorrelation observed in Figure 54 (a-d).

Table 25 Auto-Negative binomial regression statistics

	Est.	SE	IR	Pr(>|z|)	CI (95%)
Intercept	-0.522	4.873	0.593	<0.05	<0.05 - 8339
Autocovariate	1.144	0.033	3.140	<0.05	2.944 – 3.350
Riverine vegetation	2.217	0.533	9.195	<0.05	3.237 – 26.120
Precipitation	-0.014	0.005	0.986	<0.05	0.976 – 0.996
Cropland	-0.287	0.208	0.751	0.166	0.499 – 1.127
Savannah	-0.266	0.157	0.767	0.090	0.564 – 1.042
Shrubland	0.902	0.839	2.464	0.283	4.755 – 12.770
Temperature	0.131	0.214	1.140	0.540	0.749 – 1.736

In the Auto-Negative Binomial regression model, inclusion of the autocovariate reduced the significance of more parameter estimates. Cropland, savannah, shrubland and temperature had their significance grossly diminished (p>0.05), as a result of introducing the *autocovariate*. Precipitation turned out with a negative significance (IR=0.986). Only riverine/ lacustrine vegetation maintained its significance (IR=9.195) of positive correlation with tsetse abundance. Overall, riverine vegetation as a land cover covariate appeared to be the most useful of the predictor variables, followed by precipitation which had a negative significance in prediction of tsetse abundance. The residuals variogram (Figure 55b) was created using residuals from the Auto-negative binomial regression and shows an improvement with less spatial autocorrelation in the residual values.

(a) Residual spatial autocorrelation



(b) Residual variogram (Pearson)

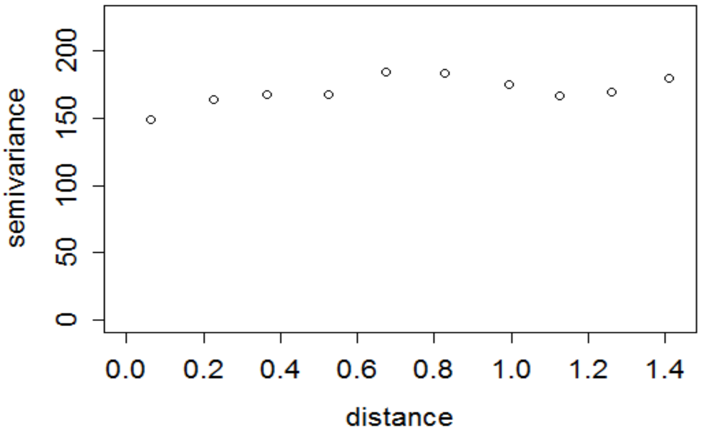


Figure 55 Spatial autocorrelation for Auto-Negative binomial

Figure 56, shows the predicted tsetse abundance across the study area based on the multivariate negative binomial regression model, while Figure 57 shows the predicted tsetse abundance based on the final multivariate Auto-negative binomial regression model. The two models identify areas of scaled tsetse abundance with estimated apparent fly densities ranging from 0 to 170.

Figure: 56, shows the clearly marked tsetse abundance zones across the study area. High tsetse abundance of above 5 flies per trap per day were associated with districts of Kalangala, Bugiri, Busia, Kamuli and Kayunga. The map shows high tsetse abundance zones as clusters especially along river Nile. This is important when planning control interventions.

Table 26, lists the average values of the predictor variables for the 7 tsetse density classes as generated from the final Auto-Negative Binomial regression model. Riverine vegetation as a landcover covariate provided a matched correlation with tsetse density classes .i.e tsetse density classes increased with increase in the proportion of riverine vegetation as a Landcover type and vice versa. Highest rainfall was associated with the highest density class. Highest proportion of exhibited savannah landcover covariate was equally matched with the lowest density class, a rejoinder which makes intuitive sense since tsetse should be less abundant in very disturbed habitats. Temperature appeared not to have a well-defined correlation with density classes. An interpretation and explanation of this outcome is addressed under discussion section.

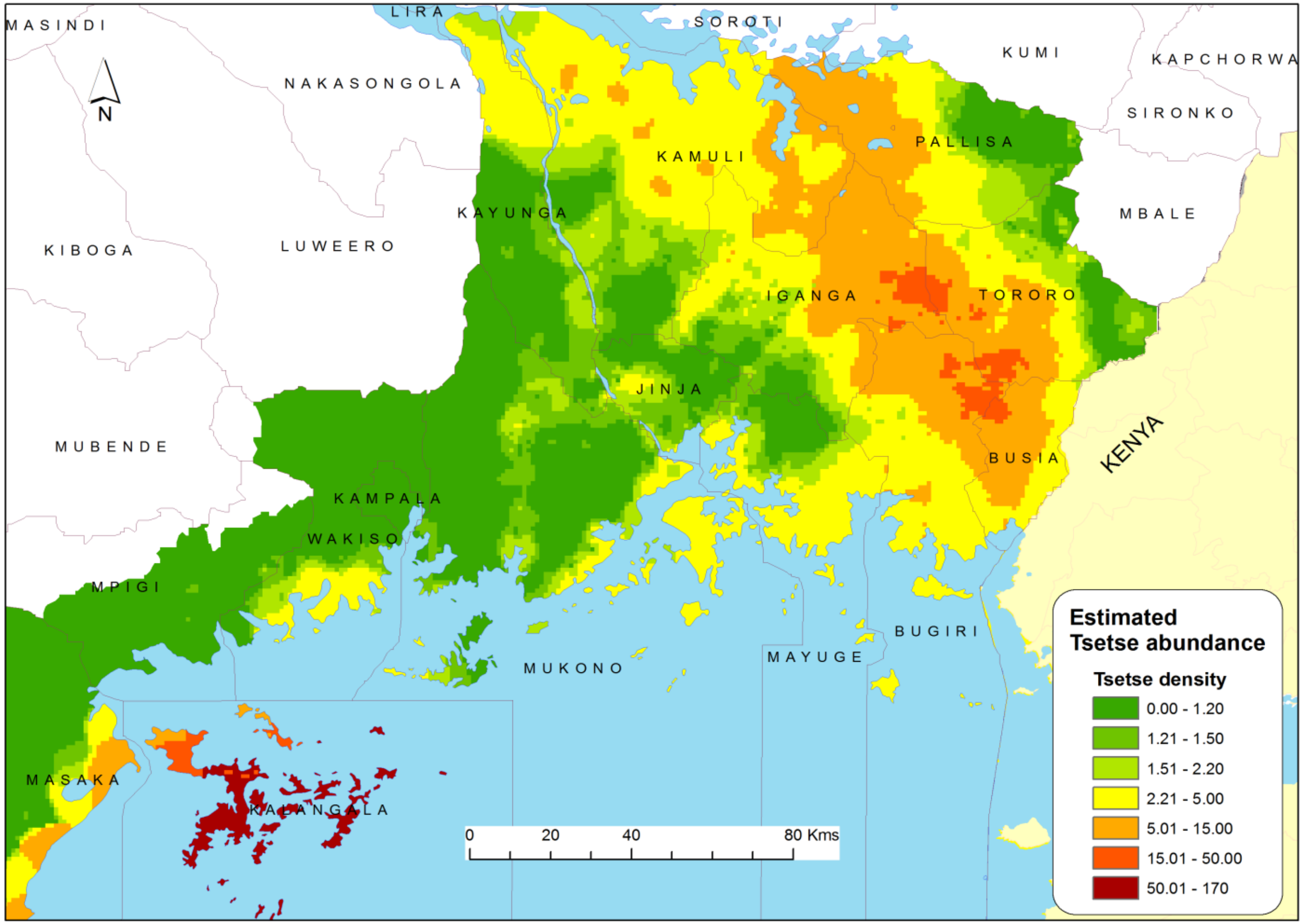


Figure 56 Predicted Tsetse abundance (apparent density) using Negative Binomial model

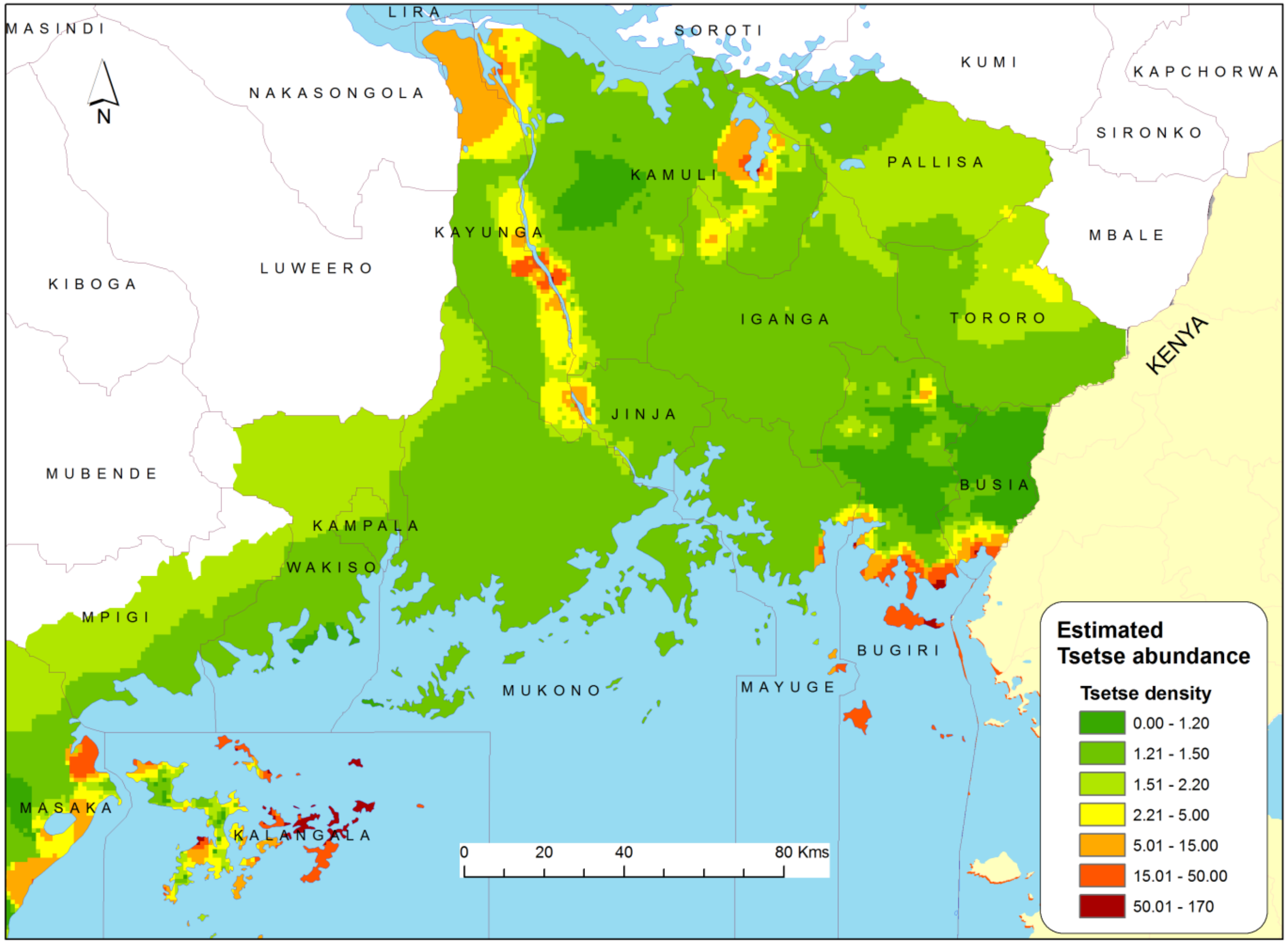


Figure 57 Estimated tsetse fly (*G. f. fuscipes*) abundance using Auto-Negative Binomial model

Table 26 Average values of the predictor variables for each of the predicted tsetse density classes based on Auto-Negative Binomial regression model

			Proportion of Landcover under the tsetse density class as a %				*Average FTD from training data for each density class*
Predicted Tsetse density class	Average Temperature	Average Rainfall	Cropland	Savannah	Shrubland	Riverine	
0.00 – 1.20	22.6	225.3	35.8	49.6	0.4	0.4	1
1.21 – 1.50	22.6	200.1	15.0	27.6	0.8	0.4	2
1.51 – 2.20	22.4	177.1	7.9	4.0	1.2	1.6	1
2.21 – 5.00	22.3	177.8	4.3	10.6	4.7	12.6	4
5.01 – 15.00	22.3	221.9	44.9	18.9	9.1	35.4	8
15.01 – 50.00	22.4	247.1	10.6	7.9	0.4	51.2	21
50.01 – 170.00	22.4	250.8	9.1	7.9	2.0	57.5	82

5.5 Discussion

The objective of the study was to develop a predictive model that can reliably inform decision-makers about the tsetse abundance in the target area within Uganda, based on entomological survey results and a set of environmental covariates represented by vegetation and meteorological data surrogates. The study was intended to contribute to solving the data scarcity problem by providing reliable sub-national tsetse data (maps) to guide control interventions. The strength of the results presented in this study is derived from the fine spatial resolution, multi-purpose satellite sensor-based data and the comprehensive tsetse count data applied. The tsetse data were entirely field-based tsetse catch data. The trend of technological advancement and the need to understand prevailing spatial patterns of tsetse flies in even the inaccessible habitats at sub-continent, national and sub-national levels, will continue to call for this kind of approach to vector mapping. For now and the near future tsetse distribution and abundance models will have to rely heavily on covariate data in form of surrogates of vegetation (Landcover & NDVI) and meteorological data (temperature & precipitation) among others (Rogers et al 1996). Similar studies leading to the successful mapping of tsetse flies in West Africa have been conducted (Hendrickx et al, 1995 and Rogers at al 1994).

There are no tsetse abundance maps for Uganda. Such a situation does not provide an opportunity to evaluate and compare the study results in terms of both similarities and differences. However under such circumstances, an attempt was made to compare the results with the tsetse presence –absence maps available (Wint (2001) and Ford and Katondo (1977)) for the purpose of identifying spatial consistence and identifying any unfamiliar or possibly new tsetse vector niches. The investigation indicated broadly similar predictions. The new map created carries the advantage of being at bigger scale (300m) as it was prepared at sub-national level.

Surrogates of vegetation and meteorological data have been correlated with vector abundance and even vector mortality (Rogers et al 1996). In the majority of previous tsetse distribution and abundance models, temperature emerges as the most important predictor followed by NDVI and then precipitation (Rogers et al 1996). These findings have to some extent been matched with results of this study. For instance, at univariate analysis stage tsetse abundance was found to be significantly correlated with eleven variables (cropland, woody vegetation, woodland, closed montane forest, open montane forest, Shrubland, shrubs on flooded land, bare areas, riverine vegetation, temperature and rainfall). Savannah vegetation, NDVI and elevation demonstrated negative correlations with tsetse abundance.

Tsetse flies thrive in areas with mean annual temperatures of 19-30°C (Terblanche 2008). Temperatures below 19°C slow down tsetse activity and general physiology (Terblanche 2008), while extreme temperatures increase fly mortality (Moore et al 2010). Tsetse are severely affected by high temperature conditions and once exposed to a temperature of more than 36°C tsetse will have a survival capacity of close to zero (Torr and Hargrove 1999). According to the data used, the lowest temperature was registered as 13.5°C, the mean temperature was 27°C and the maximum temperature recorded was 29.7°C for the study area. Temperature variation was by about 4°C at most across the region. These temperature extents have specific consequences on fly availability in the study area as they will affect tsetse fly activity and general physiology. This condition was expressed by the significant relation established between temperature values and tsetse count (p<0.05, IR=2.760), although it was not significant in the final auto negative-binomial model.

Elevation has an influence on the micro-climatic conditions of an area. The entire study area has limited height variation (1034 to 1412 m above sea level) and the model illustrates the lack of an altitudinal control on tsetse abundance within the study area. The elevation of the whole study area was suitable for tsetse with negative correlation ($p<0.05$, IR=0.993) at univariate analysis stage.

Given that this study area was sampled for *G. fuscipes fuscipes* using biconical traps only once and during a wet season (March, April & May), these data are likely to be affected by the element of seasonality. Fortunately the tsetse flies spatially disperse across the largest range during the wet season and this factor is expected to prevail and build the required confidence in the results. Never the less additional dry season entomological data would be of significant value to improvement of results.

5.6 Conclusion

Extensive, new location-specific entomological data gathered from the Lake Victoria basin of Uganda confirmed the widespread presence of *G. f. fuscipes* in the study area in S.E Uganda. The engagement of an Auto-negative binomial regression model using satellite sensor data as surrogates of traditional vegetation and meteorological data enabled the estimation of *G. f. fuscipes* abundance across S.E Uganda. The final model revealed with high certainty the outstanding role of water (riverine vegetation) in determining the tsetse abundance within the region. Such findings are expected to offer avenues for making better and targeting tsetse control interventions by local and central governments. The absence of similar data for the other parts of Uganda will curtail the extension of this type of model to a nation-wide context. However, as such data preferably with a wider variety of tsetse species are produced, such mapping procedures could be simulated easily.

Such outputs will inevitably become important tools in planning and executing of successful national AAT and HAT control interventions.

CHAPTER.6: GENERAL DISCUSSION

6.1 Introduction

Discussions have been made alongside each chapter presented in the thesis. This particular chapter considers the key findings presented in earlier chapters in a broader context. As such, discussion will be centred on the main findings of the study.

6.2 Tsetse distribution in the Lake Victoria basin

Entomological data was collected to determine the tsetse distribution and apparent density in the Lake Victoria basin. In return, the collected data was planned and actually supported the process of investigating an association between tsetse flies and the regularly measured environmental variables. Indeed the survey enabled the confirmation of tsetse presence in the basin. Three sub-species known to exist in this basin i.e. *G. f. fuscipes*, *G. Pallidipes* and *G.Brevipalpis* (Ford, 1971 and Wint, 2001) were investigated on. Results from the survey confirmed the presence of only two i.e. *G. f. fuscipes* and *G. Pallidipes*. These two sub-species differed in spatial orientation. While *G. Pallidipes* was restricted to isolated points within only three districts (Tororo, Busia and Mbale), *G. f. fuscipes* was observed to be widespread over most of the surveyed areas. The spatial pattern of *G. Pallidipes* displayed by the survey results indicates aspects of species retreat or disappearance from historical ecological zones while *G. f. fuscipes* appears to be expanding to new territories. This situation could be attributed to increased human interference in the basin (Rogers, 2003; Jorda et al 1990). A section of the natural landscape in the basin has been humanised through deforestation as a means to create land for agriculture, settlement and industrialisation. Cases of species retreat appear to be a common discovery (Adam et al. 2012; Bouyer et al. 2010; De la Rocque et al, 2001, Rogers et al. 1996).

A large number of non-tsetse flies were also trapped in the process. These are also biting flies and of interest in further understanding their possible link in transmission of trypanosomiasis. The concern remains of clarifying the high trypanosomiasis prevalence rate in some areas of Uganda despite very low levels of tsetse presence. There is need to conduct studies so as to ascertain the capacity of these biting flies in mechanical transmission of trypanosomiasis to both humans and animals. Their presence in large numbers as depicted by the survey results benchmarks an area of research attention.

6.3 Tsetse control

The findings of this study suggest that, any well planned and properly funded tsetse control intervention can reduce the tsetse and trypanosomiasis problem to zero or at least close to zero. The testimonies provided by the different short-lived projects implemented over the past 50 years in Uganda in terms of achievements are clear. For the tsetse control methods available for use (FAO, 1992 & 1993), the question of sustainability remains a challenge as it compounds the weaknesses and demeans the strengths of each control method applied. In all this, the key consideration should be to promote control technologies which are environmentally friendly, cost-effective and sustainable. This understanding led some countries to ban some tsetse control methods and their associated chemicals due to their impacts on health and environment (Serunjoji, 1976).

The use of SAT for large scale elimination of the tsetse flies has been applied in several countries, including Uganda, with success. The 2001/2002 case of

Okavango Delta in Botswana where 16,000km^2 of land infested with *G.morsitans centralis* (Machado 1970), in a period of eight weeks of SAT application in five cycles, was declared tsetse free is a clear indicator that SAT is a good tsetse control approach (Kgori, 2006). Other examples of SAT application include; Kenya (Lambwe valley in 1970 –using Diedrin), Niger (1971 – using Endosulfan), Nigeria (1977 – using Endosulfan & Diedrin), Rwanda (1976 – using Diedrin), Zambia (1972 – using Endosulfan), (FAO, 1982) Ghana and Burkina Faso in 2012 using Deltamethrin (Adam et al 2013). Unfortunately the approach is expensive and most times it is carried out with support of donor community. Above all it requires specialised teams to undertake and ensure proper environmental monitoring during and after the operations (Kgori, 2006). Current computed estimate for conducting SAT for tsetse control is $300 per Km^2 (Adam et al, 2013; Kgori, 2006).

Over time, there has been a shift to and consolidation of the use of insecticide treated pyramidal traps in tsetse control. This method is ecologically prefered to ground and aerial spraying against tsetse flies (Gouteux et al, 1995). Tsetse use a range of olfactory and visual stimuli to locate their hosts and this response is what is exploited to lure tsetse flies to insecticide-treated traps and targets and thereby killing them (Lindh et al 2012). This approach carries along with it the advantage of traps being relatively cheap and can easily be adopted by communities. The suitability and cost-effectiveness of different traps for the different tsetse species has been investigated (Abila, 2007). Abila asserts that cost has been a factor in selection of trap-type to be used for tsetse control operations in many areas. Traps have been used in several countries including; Kenya (*G. f. fuscipes and G. Pallidipes*), Congo (*G.palpalis*), Ivory Coast (*G.tachinoides & G.palpalis*) and Togo (*G.tachinoides &*

G.palpalis), (Rogers 1994). For each of these country examples, successes ranging between 75% - 99.5% of fly population reduction were registered. Unfortunately, the tendency to promote such approaches under what is currently code-named "community-based approaches" is causing the central governments to divulge their responsibility and there by leading to the misuse of chemicals whose actual impact on both human and animal health is yet to be evaluated, quantified and documented (Rogers 1994). The proper administration of dosages for trap impregnation, injectables, pour-ons and sprays remains a challenge due to partly ignorance and other reasons among communities. There is increasing research on how to improve sensitivity of existing traps and targets and how to make them more user-friendly (Gouteux et al. 1995; Abila et al. 2007). However, while these approaches to Tsetse and Trypanosomiasis control are effective and to some extent sustainable (Okoth, 1991), it is highly likely that some of them, especially those involving misuse of injectables, are contributing to aspects of drug resistance in animals (Matovu et al 2001, Van Den Bosche, 2000; Kibona et al 2006). However, for purposes of sustainability, "community-based approaches" as this could be a preferred option. Community empowerment in terms of skill and improved social welfare should be a pre-requisite.

6.4 Estimating tsetse presence

During univariate analysis, tsetse presence was found to be significantly associated with several variables (cropland, forests, grassland, shrubs, riverine vegetation, temperature and rainfall). At multivariate analysis stage, some variables lost their significance while others maintained it. Those that maintained their significance included; forests, temperature, cropland and rainfall. Riverine vegetation had a very weak association with tsetse presence and this could be attributed to the fact that the survey was done in a wet season where riverine conditions were generally not a unique constraint. During such season, tsetse spread widest (Torr et al. 2011, Leak, 1998). Similarly, rainfall (OR=1.02) and elevation (OR=1.01) were weakly associated with tsetse presence as exhibited by their respective small effects. The entire study area has limited height variation (1034 to 1412 m asl) and the model illustrates the lack of an altitudinal control on tsetse presence within the study area. Such heights are entirely within the acceptable tsetse altitudinal ranges (Leak, 1998). Temperatures in study area vary from 13.5^{0}C as lowest to 29.7^{0}C as highest. Again this is within the acceptable tsetse temperature range 19-30^{0}C (Terblanche 2008; Torr and Hargrove 1999). However after diagnosing the residuals, the ordinary logistic regression proved to be inadequate due to presence of spatial autocorrelation. This called for the introduction of an Autocovariate component into the ordinary logistic regression model to increase the overall model accuracy to a significant level (**Autologistic regression**).

Autologistic regression is of pronounced value as a modelling tool because it employs an extra variable (autocovariate) whose function is to capture the effects of other response values in the spatial neighbourhood. Carsten (2007) asserts that neighbouring values are expected to be similar to the focal value for ecological reasons such as dispersal, which will lead to higher abundance of off-springs near the parent organism. Thus, due to such spatial control, Autologistic regression enabled the detection of key environmental variables that are highly associated with tsetse presence and these were; forests ($p<0.05$, OR=1.105) and riverine vegetation ($P<0.05$, OR=1.008). Autologistic regression established the absence of a significant association between tsetse presence and variables like cropland ($p<0.118$), temperature ($p=0.871$) and rainfall ($p=0.445$). Elevation ($p<0.05$, OR=0.997) had a weak negative significance. Implicitly, the spatial dependence parameters for temperature, rainfall and cropland appeared less important after accounting for the effect of both forest cover and riverine vegetation.

Compared with Wint (2001) model, these results depict a reduced coverage of tsetse presence by 20-30%. All this is largely attributed to the changing land uses in the study area.

6.5 Estimating tsetse abundance (apparent densities)

Knowledge of tsetse abundance or apparent density for an area is very crucial in planning successful tsetse control interventions (Vreysen 2005; Bouyer 2010; Hendrickx et al 1999a; Rogers & Randolph 1986). Such knowledge will act as a guide in accurately targeting the interventions or appropriate control tactics. One other fundamental objective of this study was to develop a predictive model that could reliably inform decision-makers about the tsetse abundance in the target area within Uganda, based on entomological survey results and a set of environmental covariates represented by satellite sensor-derived vegetation and meteorological surrogates. Similar studies have been carried out to try and associate tsetse abundance with environmental variables (Hendrickx et al 1995; Rogers et al 1994 & 1996; Robinson et al 1997a &1997b). In most of the tsetse distribution and abundance models, temperature emerges as the most important predictor followed by NDVI and then precipitation. This particular study identified riverine vegetation as the key variable influencing tsetse abundance in the Lake Victoria basin. The cause for none-match of environmental variables of other studies compared with these study findings could be attributed to differences in attendant tsetse species and their respective environmental preferences. Long-term climatic conditions experienced in an area leading to tsetse adaptation is yet another.

Poisson regression and the Negative Binomial regression were considered for estimation of tsetse abundance in the region. These two methods are commonly considered for statistical analysis of count data (Dohoo et al. 2010; Hosmer & Lemeshow 1989a). The two methods were evaluated and Negative binomial regression appeared most suitable. Negative binomial regression was used since it had the ability to account for the overdispersion (identified among data). At univariate analysis tsetse abundance was found to be significantly associated with several variables including; cropland, woodland, Shrubland, shrubs on flooded land, riverine vegetation, temperature and rainfall all with P_value below 0.05 and OR>1.

The **multivariate Negative Binomial regression** showed that the tsetse abundance was positively correlated with temperature, riverine vegetation, shrubland, cropland and rainfall. This implies that most of the variables retained their significance in influencing tsetse abundance. However after diagnosing the residuals, the non-spatial Negative Binomial regression proved to be inadequate. There was evidence of spatial autocorrelation in the residuals. Similarly, an Autocovariate was introduced in the model to increase accuracy (Auto-Negative Binomial regression).

In the **Auto-Negative Binomial regression** model, inclusion of the autocovariate reduced the significance of more covariates. Cropland, savannah, shrubland and temperature had their significance grossly diminished (p>0.05), as a result of introducing an *autocovariate*. Precipitation turned out with a negative significance ($p<0.05$, IR=0.986). Only riverine/ lacustrine vegetation maintained its significance ($P<0.05$, IR=9.195) of strong positive association with tsetse abundance. Overall, riverine vegetation as a land cover covariate appeared to be the most useful of the predictor variables, followed by precipitation which had a negative significance in prediction of tsetse abundance.

The two models were assessed by computation and examination of the deviance as an approximate goodness-of-fit test, comparison of residual deviance with the X^2 distribution, examination of the Akaike information criterion (AIC) score and (iv) examination of different residual plots (Dormann and Bivand, 2008).

6.6 Study limitations

1. Given that this study area was sampled for *G.fuscipes fuscipes* using biconical traps only once and during a wet season (maximised spot data), these data are likely to be affected by the element of seasonality. Fortunately the tsetse flies spatially disperse widest during the wet season and this factor is expected to prevail and build the required confidence in the results. None the less additional dry season entomological data would be of significant value to improvement of results.

2. At least three tsetse species were expected from the surveyed region i.e. *G. f. fuscipes*, *G. Pallidipes* and *G.brevipalpis* (Ford, 1971 and Wint, 2001). However, only two of the three were visible (*G. f. fuscipes* and *G. Pallidipes*). And even the two had different spatial patterns. *G. f. fuscipes* was widely spread while *G. Pallidipes* was restricted to very limited

locations. This situation motivated the study to be restricted to *G. f. fuscipes* in general.

3. The entomological data was the key factor in delimiting the extent of the study area. Thus wider predictions could not be afforded due to limited spatial coverage during entomological survey. Only approximately 40,000Km^2 of ground area is covered by the study area. This is only about 20% of the entire country.

4. While the different model results have been statistically validated, there should have been additional validation in form field ground-truthing or at least a test on the most current tsetse catch data (2014) as a means to further confirm the strength and relevance of the results to date.
5. The study did not compare Autologistic regression as a method used to correct for spatial autocorrelation with other possible methods like; ; (i) GEE-general Estimating equations (ii) ME-mapping of eigenvectors (iii) SGLMM-spatial generalised linear mixed models and (iv) SBM-spatial Bayesian models (Dormann, 2007 In Carsten 2007). Such alternative methods mainly used in ecological modelling studies do account for spatial autocorrelation in ecological data.
6. Spatial resolution of the landcover layer was unable to allow detection of small rivers / water bodies. This affected the results.

6.7 Decision support to tsetse and trypanosomiasis control

One of the greatest problems for sub-Saharan Africa is shortage of epidemiological data to support planning for provision of adequate public and animal health services. Where such data exists, it is often out-dated, incomplete and non-standardised. This curtails service delivery for the already over-burdened health systems of rural Africa. The overriding challenge is how to provide the needed resources to facilitate the process of regular data collection in support of disease surveillance and vector monitoring across target regions. Due to such circumstances, there is currently an increasing search and interest towards devising cheaper but yet significantly reliable means for availing the needed epidemiological and vector data for planning purpose. This study enabled the development of epidemiological models that predict tsetse vector distribution and abundance. Knowledge of vector distribution and abundance is fundamental in planning successful tsetse control interventions.

The successes registered during the 1980s should act as an example of the possible tsetse and trypanosomiasis control approaches that could be emulated. These approaches had a lot of impact and were largely community based with limited sequential aerosol techniques for some few areas. There is need to ensure population protection using affordable approaches.

6.8 Future research priorities

There is need to complete the investigation through providing answers to the under listed.

- From 'where are the tsetse flies' to "**Where are the infected flies**"?
- From 'how many tsetse flies' to "**How many flies are infected**"?
- From mapping the tsetse vector to quantifying the tsetse vector burden
- Characterisation and quantification of groups at risk due to tsetse presence and abundance (people, animals, geography & poverty)
- Extension of similar work to cover entire country with focus on Sleeping sickness foci.

CHAPTER.7: CONCLUSION AND RECOMMENDATIONS

7.1 Conclusion

This work contributed to an improved understanding of the relationship between environmental variables and tsetse presence / abundance within the Lake Victoria basin. The main finding was that the presence of forests to the greatest extent and water bodies forming the riverine and lacustrine vegetation to a lower extent are key in positively influencing the presence of *G. f. fuscipes* in an area. On the other hand tsetse abundance was found to be greatly enhanced predominantly by the presence of riverine and lacustrine vegetation. An equally important finding is that, for tsetse abundance again, rainfall as an environmental variable presents a weak negative influencing power just like elevation is for tsetse distribution. These findings come as a confirmation to available literature on the factors known to influence tsetse presence and abundance. The universality of these tools in measuring the relationship between environmental variables with other tsetse species remains to be tested. But this study finding offers space for intellectual speculation that the tool is universal and that it can successfully be applied on all tsetse species. Therefore the limited knowledge of tsetse distribution as a factor contributing to absence of tsetse control activities by various governments or communities could easily cease to be a demanding issue. The tools should be able to bridge the existing national data gap on tsetse vector distribution and abundance to facilitate better and timely planning of tsetse eradication and trypanosomiasis elimination interventions.

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Appendices

Appendix 1

Data Collection Protocol

A review of past tsetse and trypanosomiasis control efforts in Uganda (1960-2010)

Data Collection Protocol

The data collection exercise shall follow the following steps:

- Development of a data collection plan
- Development of a data collection action plan
- Collection of data
- Analyzing and synthesizing of the collected data
- Storage of the collected and analyzed data

Data Collection Plan

- Consult COCTU , MAAIF and Ministry of Health regarding access to needed data
- Complete a Data collection plan

Data collection action plan

- Complete a **Data collection plan**

Collection of Data

Before collecting data:

- There will be identification of potential data collection challenges and the precautionary measures to maintain the integrity of the study.
- Proper methods for collection, storage and retention of data will be designed.

During data collection

- Data request forms will be filled and used
- Monitoring of data collection activities will be undertaken closely for completeness.

Analyzing and Synthesizing of the collected data

Before

- Tools to support and benefit the data analysis process will be identified and applied based on the data collected
- List of analysis tasks will be drawn and handled.

During

- There will be verification of data collected for completeness and if it is sufficient.
- There will be review and refinement of processes as necessary.
- There will be identification of possible errors in data and appropriate measures will be taken to correct them.
- Templates for reports, charts and graphs will be prepared.

Storage of the collected and analyzed data

Before

- Design a process and mechanism for data storage involving both electronic and none electronic means.

During

- Adhere to the designed process and mechanism for data storage
- After the data collection is complete, remove all copies of the data from digital storage locations (disk drives) and store a copy of all reports and collected data in a secure location.
- Analysed electronic data will be stored on Shared CD Rom drive on Server for easy access to use by all stakeholders
- Data generated and that rescued from extinction (dilapidated records) will be upgraded and filed and maintained in their respective archives or delivered at the central COCTU Records office / Library.

The Data Collection Plan

Justification

The purpose of the data collection is to obtain information that shall be analyzed to form part of a review of past tsetse and trypanosomiasis control efforts in Uganda (1960-2010). This serves as a requirement for the thesis chapter, under the PhD study. But as result is expected to inform researchers and policy makers about what has happened before and how it could be of benefit to planning for the future.

Data collection design and process

Data collection design and process

The study will involve collection of data using two main methods, (i) Interviewing and (ii) records /document search. Data will be collected by the researcher himself but will occasionally be supported by two research assistants to cover especially distant respondents within Uganda and overall to mobilize and sort records. Where Assistants will be engaged in interviewing, forms and templates of structured questions will be given to them to ensure that the actual targeted information is collected.

Records search and review method	Interview method
This will be the main source of secondary data. The expected sources of such data will be; **C. Published reports** • By COCTU, MAAIF & MoH • By local Governments • By UBOS in form of Statistical abstracts, census reports and other reports. • Journals, magazines and periodicals.	*Interviews will be of a Focused /semi-structured type and will be aimed at tapping particular experience, motivation and opinion of selected informants. This will be the main source of primary data* **Expected informants for proposed interviews are;** • Senior serving government officers in MAAIF & MoH • Long-serving district staff .i.e entomologists,

• Works of research institutions and Universities etc. **D. Un-Published reports** • Records and statistics maintained by various departments / projects at districts and headquarters (MAAIF, MoH & COCTU). Eg project reports, quarterly reports, conference papers, and ministerial reports. • The research works carried out by scholars / researchers / professionals.	health officers, veterinary officers and vector control officers • Tsetse and trypanosomiasis experts from LSTM, LSHTM, UoE, FAO, WHO, IAEA, AU-PATTEC & AU-IBAR • Retired senior tsetse and trypanosomiasis personnel • Coordinator – NSSCP (MoH) • Tsetse and trypanosomiasis Project Coordinators • Research institutions like Makerere and NaLIRRI (formerly EATRO) • Commercial Livestock farmers from selected regions.

Data accuracy

All data gathered especially secondary data, will be scrutinized for its reliability, suitability and adequacy using data exploratory methods.

Analyzing and synthesizing data

- Raw data will cleaned, sorted and quantitatively be analyzed using statistical method by the researcher.
- Some data(maps) that is for digitizing will be digitized

Data storage and records management

Storage of electronic and non- electronic data:

a. Analysed electronic data will be stored on Shared CD Rom drive on Server for easy access to use by all stakeholders

b. Data generated and that rescued from extinction (dilapidated records) will be upgraded and filed and maintained in their respective archives or delivered at the central COCTU Records office / Library.

Data Collection Action Plan

Activities: Steps to be taken	Persons Responsible	Persons Involved	Resources Needed	Time Line

Data request form

Name	Institution / Organisation	Address / Email

Specific Data Required:
Delivery Format:

Approval:

This data collection has been requested for by Albert Mugenyi (PhD \Student) Approval of data collection has been provided by COCTU as undersigned:

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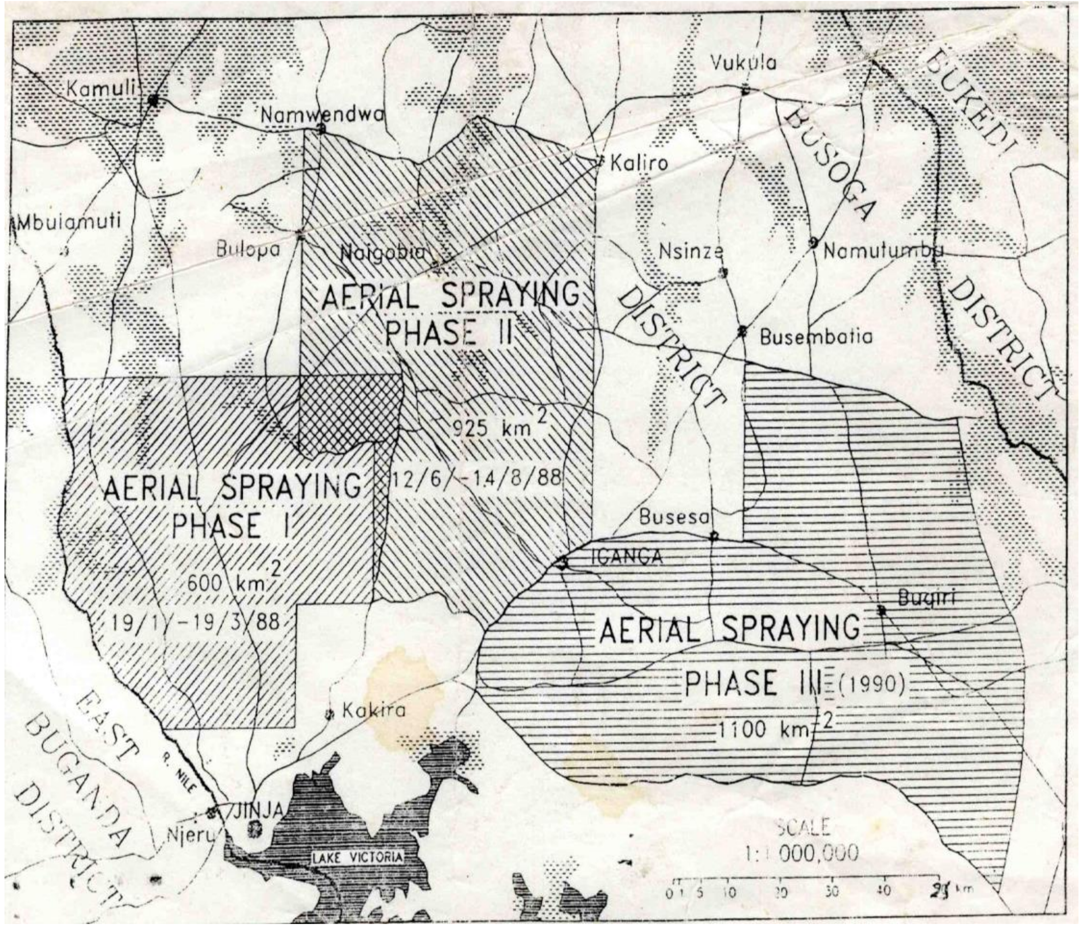
Appendix 11

AERIAL SPRAYING ZONES IN SE UGANDA 1988-1990 (PHASES-I, II & III)



Appendix 111

TSETSE SURVEY SHEET

GRID ID		TEAM LEADER		MONTH	
DISTRICT		DATA OFFICER		YEAR	
SUBCOUNTY		DATE OF ENTRY		MAP DATUM	
PARISH		ACCURACY		UTM ZONE	
VILLAGE					

Trap no.	Long	Lat	Altitude	Vegetation	Start date	Start time	End date	End time	Tsetse flies				Biting flies		Other	
									Species	Males	Females	Unidentified sex	Family	No.		Remarks