Student thesis series INES nr 292

The influence of water proximity on land cover, tree species and tree functionality in a small-holder agroforestry system

A minor field study in Trans Nzoia County, NW Kenya

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2013

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Sabina Berntsson and Josefin Winberg (2013). The influence of water proximity on land cover, tree species and tree functionality in a small-holder agroforestry system. A minor field study in Trans Nzoia County, NW Kenya. Bachelor degree thesis, 15 credits in *Physical Geography and Ecosystem Analysis*. Department of Physical Geography and Ecosystems Science, Lund University

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Bachelor thesis

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Cover picture – Trans Nzoia river (Sabina Berntsson)

Abstract

A large and rapidly growing population in Kenya together with increasing demands put heavy pressure on the country’s resources. Primary to produce enough food but also to meet other needs such as access to timber and firewood. A large part of the population relies on yields from their own farming for their survival. The farms are generally small and the needs many which makes it important to get out as much as possible from a limited space. A common alternative is to plant trees and implement agroforestry. Agroforestry trees are often multi-functional, but they have different main usages and the high competition of land force the farmers to select how they use their land and their agroforestry systems carefully. It is important to remember that even though tree planting can contribute to food security; it is not always a direct source of food and trees also consumes resources such as nutrients and water.

The aim of this study was to investigate how water proximity influences land cover, the distribution of tree species, and the main functions of the trees (Fiber, Firewood, Fodder or Fruit) in an agro-ecosystem in Hututu settlement, Trans Nzoia County, Kenya. Further, land cover maps over five settlements in Trans Nzoia were ground truthed. User’s accuracy, producer’s accuracy, overall accuracy, and Kappa value were calculated and evaluated for all maps. Through these results together with interviews and field observations was the study area in Hututu settlement selected and a detailed land cover map created.

The results show that water proximity has an influence on land cover to some degree, but since small-scale farmers mainly tries to meet their own needs can maize and beans, the staple food in Kenya, be seen everywhere. The same result can be seen for tree species, and especially when Eucalyptus is considered which the most common tree species in the area is. Tree functionality is indirectly influenced by water proximity and it can be concluded that trees that requires less management often grow close to the water courses. Further, the land cover classes *Woodland* and *Shrubland* occur more frequently in these areas.

After field observations, the proximity to buildings was also investigated as an alternative factor that influences land cover and how trees are distributed. By that investigation it could be seen that woody land cover classes have a positive relationship to closeness to buildings and that fruit trees generally are planted close to the houses.

Keywords: Agroforestry, land cover, small-scale agriculture, water proximity, tree functionality, ground truthing, GIS, Kenya, physical geography

Sammanfattning

En stor och växande befolkning i Kenya tillsammans med ökande behov skapar ett stort tryck på landets markresurser. I huvudsak för att producera tillräckligt med mat men också för att uppfylla andra behov så som efterfrågan på timmer och ved. En stor andel av Kenyas befolkning är beroende av skörden från sina egna gårdar för att kunna överleva. Gårdarna är generellt små och behoven många och detta gör det viktigt att få ut så mycket som möjligt från en begränsad yta. Ett välanvänt alternativ för att uppfylla detta är att plantera träd och implementera trädjordbruk, agroforestry. Varje agroforestry träd har ofta flera funktioner, men ett visst huvudsakligt användningsområde och konkurrensen om markyta gör att bonden måste välja sitt system noggrant. Det är viktigt att komma ihåg att även om trädplantering kan bidra till ökad matsäkerhet så är det oftast inte någon direkt källa till mat och träden konsumerar också resurser så som näring och vatten.

Syftet med den här studien var att undersöka hur närheten till ett vattendrag påverkar markanvändning och distributionen av utvalda trädfunktioner (Timmer, Ved, Foder, Frukt) i ett jordbruksekosystem i Hututu samhälle, Trans Nzoia kommun, Kenya. Vidare gjordes en kvalitetsutvärdering av markanvändningskartor över fem samhällen i Trans Nzoia kommun. Klassningsnoggrannhet, objektsnoggrannhet och total noggrannhet samt Kappa utvärderades för samtliga kartor. Genom dessa resultat, intervjuer och fältobservationer valdes ett lämpligt studieområde i Hututu samhälle ut, och en detaljerad markanvändningskarta skapades.

Resultatet visade att närheten till vatten påverkar markanvändningen i viss mån men eftersom småskaliga jordbrukare i första hand försöker tillgodose behoven på den egna gården odlas baslivsmedel såsom majs och bönor överallt i området. Samma resultat kan ses för träd, framförallt för Eukalyptus som är det vanligaste trädet i området. Trädfunktionerna påverkas indirekt av vattentillgängligheten och det kan konstateras att träd som kräver mindre skötsel ofta växer utmed vattendragen. Vidare är markanvändningsklasserna *Woodland* (skogsmark) och *Shrubland* (buskvegetation) mer frekvent förekommande i dessa områden.

Efter indikationer observerade i fält utvärderades närheten till byggnader som en alternativ faktor till att påverka markanvändning och hur träd är fördelade. Denna undersökning visade att trädliknande markanvändningsklasser har ett positiv förhållande till närheten till byggnader och att träd som producerar frukt generellt planteras nära husen.

Nyckelord: Agroforestry, trädjordbruk, marktäckning, småskaligt jordbruk, vattentillgänglighet, trädfunktioner, kvalitetsutvärdering, GIS, Kenya, naturgeografi

Preface

This study was founded by a scholarship from the Swedish International Development Cooperation Agency, Sida, and performed as a Minor Field Study (MFS). The MFS Scholarship Programme is intended to improve the knowledge level of Swedish students about developing countries and development issues, thus promoting international understanding and promote interest in Swedish international cooperation. Another objective is to improve the cooperation between departments at Swedish universities and institutes or organizations in developing countries.

The study was performed in cooperation with the non-governmental organization Vi Agroforesty in Kitale, Kenya, the Swedish University of Agriculture Sciences SLU and the World Agroforestry Center, ICRAF. The mission of Vi Agroforestry is to increase the yields and hence the economic growth of small scale farmers by educate, support and guide them in how to integrate agroforestry in the agriculture and what benefits it can gain (Vi Agroforestry, 2012). This study is a part in a cooperation project between Vi Agroforestry, SLU and ICRAF aiming to assess some of the multiple functions of agroforestry systems and identify potential synergies and goal conflicts. The research project focus on three different scales; field, farm and landscape scales, and this study was a startup on the work at landscape level.

As a part of the MFS Scholarship Programme the purpose of the study was to gain knowledge and field experience in a developing country. The field work was conducted in five settlements (Botwa, Hututu, Sinoko, Wehoya and Yuya) in Trans Nzoia County during the spring of 2013. It aimed to investigate the relationship between water proximity and land cover and tree functionality to understand if and how it influence the decision making at small-scaled farms and thus the design of the landscape. In the long run it will hopefully contribute to improve the livelihood for small-scale farmers.

The study was conducted by two persons and both take equally responsibility for all chapters.

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1. Introduction

About 80 percent of the food consumed in sub-Saharan Africa derives from small-scale[1] farms and a large proportional of the hungry people in the world are small-scale farmers (HLPE 2013; FAO 2012). Improvement in this type of agriculture therefor have large potential effect to increase the food security[2] in the world (HLPE 2013; FAO 2012). Even if there is a general decrease of undernourishment in the world, the number of people suffering from chronically hunger is still unacceptable high and increasing in some countries (FAO et al. 2012). In Kenya there was an increase of 46.3 percent between the years 1990 and 2012 (FAO 2006).

Kenya's population is large and rapidly growing. The population increase in Trans Nzoia County is larger than in the rest of the country due to its favorable agro-climatic conditions (NEMA 2009). More people sharing the same resources increase the pressure on the ecosystems. Over 90% of the households depend on wood for cooking which has contributed to extensive deforestation in the area (NEMA 2009). Facing global climate change, the challenge of feeding an increasing population when resources are limited and already highly exploited, enhances the importance of sustainable agriculture (Wallace 2000). In Trans Nzoia County, where the irrigation possibilities are low, the majority of agriculture is rain fed. Several methods to increase the water use efficiency are suggested, and one of the most popular in Kenya is agroforestry systems (Wallace 2000).

Agroforestry has the potential to improve water productivity by increasing the proportion of water used for tree or crop transpiration and improve the productivity of the water used (Ong et al. 2006). Prevalence of trees changes the micro-climate around the crop with increased humidity through declining radiation and temperature. However, knowledge about which combinations of trees, crops, soils and climate that are suitable for a specific location is necessary to avoid competition (Wallace 2000). The trees used in agroforestry are often multi-functional, but can be divided into main functionalities such as fruit, fiber, firewood, and fodder. The positioning of these trees in the landscape and the design of the agroforestry systems are mainly influenced by preferences by farmers and the size of the farm (Biggelaar 1996). The average size of a farm in Trans Nzoia County was 0.9-2.0 ha in 2006, but increasing population density makes further subdivision necessary (Orodho 2006). The high competition for land in limited space forces farmers to select their agroforestry systems carefully, and it is important to remember that even though tree planting can contribute to food security, it is not necessary a direct source of food.

In this thesis water proximity[3] is investigated as one biophysical factor that can influence land cover[4] and tree functionality. Water proximity is here equated with closeness to water bodies since the result from this study show that distances is essential for farmers' possibilities to water their crop due to the conditions in the area (for more information see section 7.3). After field observations, the proximity to buildings and its impact on planting choices was also investigated. The accuracy of land cover maps over settlements in Trans Nzoia County have

[1, 2, 3, 4] For definition see Appendix I been evaluated, and a detailed land cover map was created for a selected study area in one of the settlements to obtain accurate maps over land cover and tree functionality.

Aim

The aim of this thesis is to investigate how water proximity influences land cover, which trees that are planted, and tree functionality in a small scale faming landscape in Hututu settlement, Trans Nzoia County, Kenya. Further, the aim is to address additional alternative factors that are important for the design of the landscape.

To get reliable data for the investigation, the study also includes accuracy evaluation of land cover maps of five settlements in the county and creation of a detailed land cover and tree functionality maps of a study area in the settlement with highest map accuracy.

Outline of the text

The second chapter gives an overview of the study area through background information about Kenya as a country, Trans Nzoia County, and Hututu settlement where the detailed study was conducted. It is followed by background information about Agroforestry, tree functionality and the four agroforestry groups "fiber, firewood, fodder and food" in Chapter 3. In this section information about the crops grown in the area is also found. Chapter 4 describes the theoretical background, both regarding remote sensing and the methods used for the accuracy assessment. This is followed by description of the data in Chapter 5 and the method in Chapter 6. The results are presented in Chapter 7, and Chapter 8 discusses the results and methods used in this study. Finally, the conclusions are found in Chapter 9.

Five complementary appendices are found in the end of the report. Appendix I consists of a definition list where difficult terms and abbreviations are defined. The list is followed by descriptions of Tree species characteristics in Appendix II, after the interview done with William Makokha. Appendix III is the classification key that was used when ICRAF created the land cover maps that were evaluated and used in this study. These maps are found in Appendix IV in alphabetic order (Botwa, Hututu, Sinoko, Wehoya, Yuya). At last, Appendix V includes Error matrices that were created during the map evaluation process.

2. Study area

The study was carried out in Trans Nzoia County that is located in north western Kenya (Fig. 1). Land cover maps were evaluated in five different settlements within the county, Botwa, Hututu, Sinoko, Wehoya and Yuya (Fig. 2). A smaller study area in Hututu settlement was later chosen for further analysis of the land cover and trees in the landscape and how it is influenced by water proximity (Fig. 3).

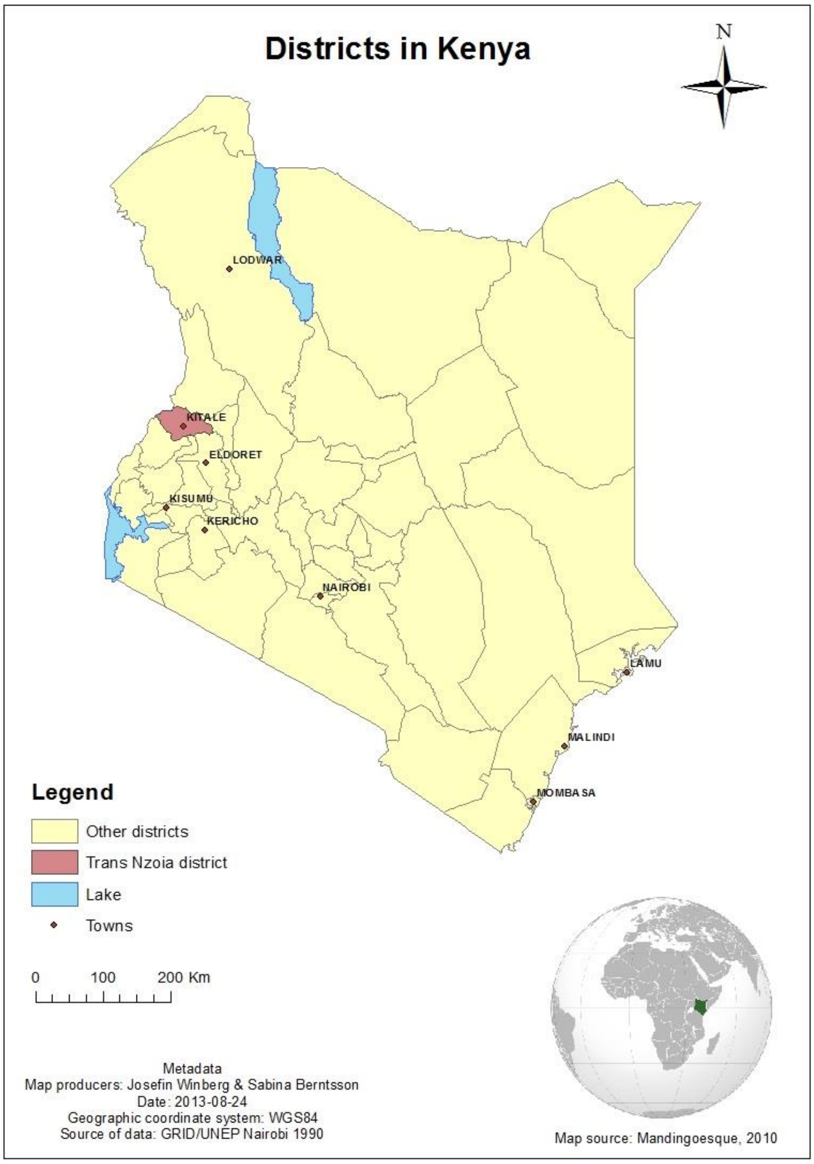

Figure 1: Administrative map of the district in Kenya with Trans Nzoia highlighted. Kenya´s position in Africa is showed on the globe to the right.

2.1 Kenya

Kenya is situated in eastern Africa and borders to Tanzania, Uganda, South Sudan, Ethiopia and Somalia (CIA 2013). Kenya is a former British colony and became independent in 1963 (BBC 2012). The area of the country is 580 367 km^2 and it is separated into seven provinces; Central, Coast, Eastern, North Eastern, Nyanza, Rift Valley and Western; and one area, Nairobi Area (CIA 2013), this is then further sub-divided into district. The population size in Kenya is about

43 million people, but it increase every year with a population growth rate of 2.6 % (UN 2013). The capital city, Nairobi, is situated in the south-central part of Kenya and has a population of 3.4 million people (UN 2013).

2.1.2 Agriculture

Agriculture plays a key role in Kenya's economy by being the largest contributor to Kenya's gross domestic production, GDP[5] (Library of Congress 2007). In 2012 the GDP of Kenya was 1800 USD per capita, whence agriculture accounted for 24.2 % (CIA 2013). In addition, it employs the majority of the population (Library of Congress 2007). The most important export products are tea, coffee and fresh flowers; but fruits, vegetables, sisal and cotton are also important cash crops. The major crops for domestic consumption are maize and wheat (Britannica 2012).

Only 8 % of the total land cover in the country is constituted by agriculture, and the majority of the fields are smaller than 20 000 m^2 (NE 2012). The increasing population in the productive areas of Kenya have led to a decrease in farm size and the average size in these areas was 9 000-20 000 m^2 in 2006 (Orodho 2006). The main part of the agriculture is concentrated to the fertile highlands in western Kenya (Library of Congress 2007). Despite the importance of agriculture to the economy of Kenya, the lack of water, infrastructure and arable land (NE 2012; Britannica 2012), together with land degradation and low agricultural development restrain further expansion (Ekbom et al. 2013).

At a national level, Kenya is a country with a negative nutrient balance where more nutrients are being mined from the soil than what is returned to it (Vlaming et al. 1997). This has led to a downward trend in food production per capita (De Jager et al. 1998), a problem of increasing magnitude in combination with Kenya’s growing population (Vlaming et al. 1997).

2.2 Trans Nzoia County

Trans Nzoia County is an administrative district in the Rift Valley Province in Kenya (Fig. 1). The total area of the county is 2487 km^2 of which about 2000 km^2 is arable land (Kagai, 2011), and the population size 818 757 (KNBS, 2009). The largest city and the county capital is Kitale (Soft Kenya, 2012) which has a population size of 75 123 (Geonames, 2013). The dominant soil type in Trans Nzoia County is Ferralsols (Medvecky, *et al.*, 2007).

The main economic activity in the county is agriculture and the most common crops grown are maize (*Zea mays*), beans (*Phaseolus vulgaris*), potatoes (*Solanum tuberosum*), sweet potatoes (*Ipomoea batatas*), sorghum (*Sorghum bicolor*), cassava (*Manihot esculenta*) and fingermillet (*Eleusine coracana*) (Kagai 2011). Trans Nzoia County is one of the most important maize production areas in Kenya (O´Callaghan et al. 1994). Horticultural products like vegetables, fruits, nuts, and flowers are produced for both local market and for export (Kagai 2011). An additional source of food and income is dairy farming which is widely applied in Trans Nzoia County (Kagai 2011).

[5] For definition see Appendix I

The practice of agroforestry is commonly seen as trees like Sesbania (*Sesbania sesban*), Calliandra (*Calliandra calothyrsus*) and certain timber and fruit trees are planted together with crops or along the farm borders (Haldin et al. 2000). The potential of Trans Nzoia County to produce food is large, but many farmers are still experiencing food insecurity (Kagai 2011).

2.2.1 Climate

The climate in Trans Nzoia County is highland equatorial with an annual rainfall of 700 to 2100 mm and a mean daily temperature that can vary between 10°C to 37°C (Kagai 2011; NEMA 2009). The mean annual temperature in the county is 18.6°C and the mean annual rainfall 1296 mm yr^{-1} (NEMA 2009). The climate is separated in two rainy seasons with dry conditions in between, the long rains normally stretches from March to April and the short rains occurs in October (Kipkorir et al. 2007). Highest precipitation rates are received at the western slopes of Cherengani and Mt. Elgon (NEMA 2009).

2.3 Settlements

Trans Nzoia County can be further subdivided in to settlements and this study were conducted in five of them; Botwa, Hututu, Sinoko, Wehoya, and Yuya (Fig. 2). The settlements have all been used for maize monoculture during the colonial time and the main land use[6] today is still agriculture but it is small-scaled.

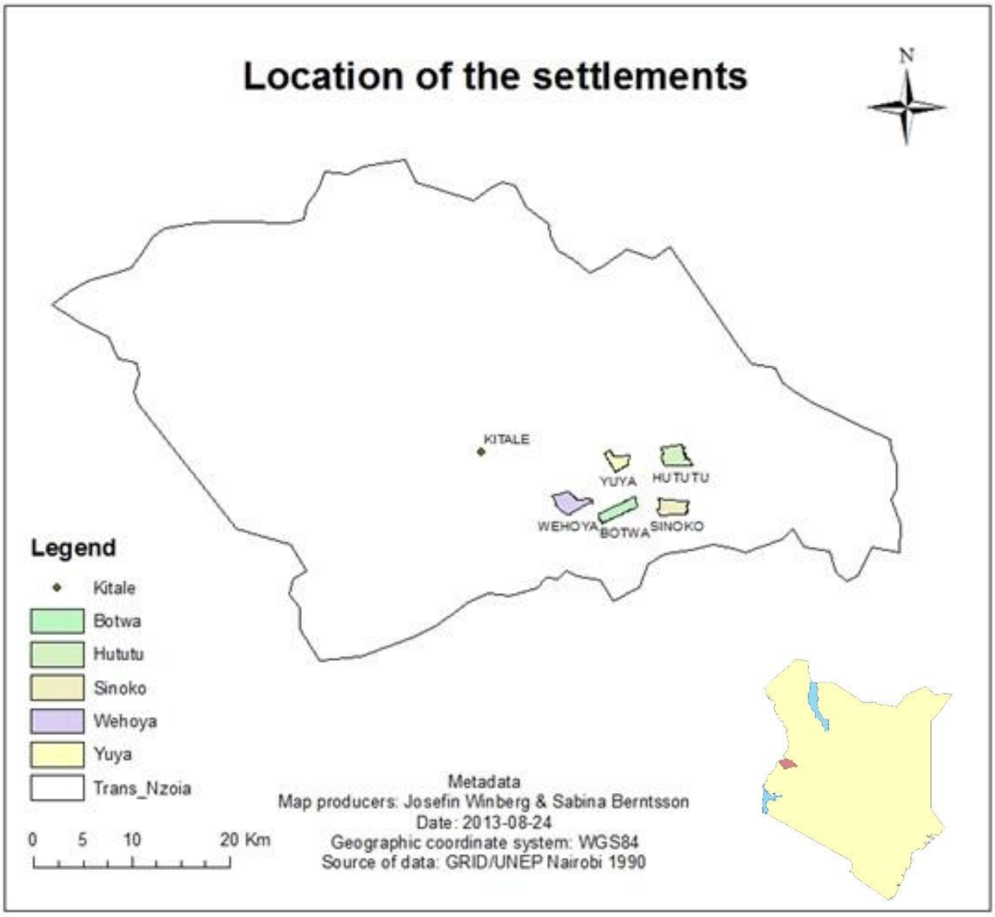

Figure 2: The location of the settlements, Botwa, Hututu, Sinoko, Wehoya, and Yuya in Trans Nzoia County.

[6] For definition see Appendix I

2.3.2 Hututu settlement

From the five settlements was a study area in Hututu selected for more detailed study of land cover and trees and how it is influenced by water proximity (Fig. 3). Hututu settlement is located in the Southeast part of Trans Nzoia County, bordering to River Nzoia. The settlement has an area of 4.9 km^2 and the interview held with Wamalwa (2013) revealed a population size of approximately 600 households. The selected study area is about 0.6 km^2 in total (601 858.4m^2) and partly borders to River Nzoia.

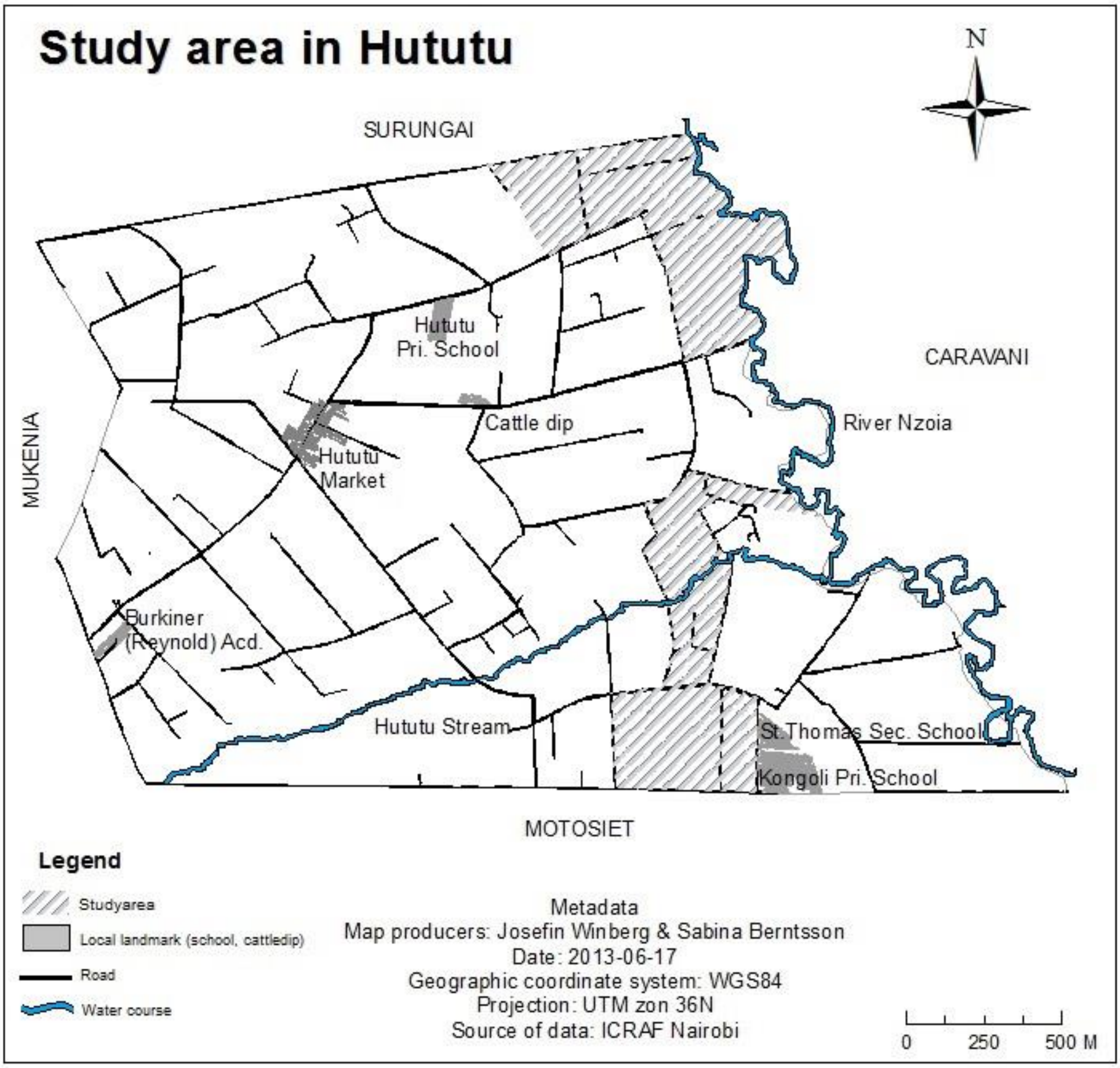

Figure 3: Administrative map over Hututu settlement showing the roads, local landmarks, water courses and surrounding settlements. The study area is marked by grey stripes.

The main land use in Hututu is small-scaled agriculture and what is cultivated is foremost based on the consumption in the own homestead (Makokha, 2013). Further Makokha also told that the most common crops in the area are maize and beans that often are planted together and constitute the main food source for most of the people. The farmers mainly plant late maturing hybrid varieties of maize that have high yield potential (Kirungu et al. 2002). The maize is planted during the start of the rain season (March-April) and then occupies the land for 8-9 months. After the harvest the land lies in fallow during the dry months, and livestock are often let out to graze the maize stovers in the field (Kirungu et al. 2002). The remaining maize stovers are subsequently collected to be used as firewood before the land is prepared for the next maize crop (Kirungu et al. 2002).

From the interview with Wamalwa and Makokha (2013) it is revealed that millet, banana, cassava, and sweet potatoes are other common crops which can be harvested when no other food is ready. The tree cover in the settlement is sparse and lack of wood has become a problem during later years (Wamalwa 2013). During the colonial time was the tree cover in the settlement dense, with indigenous trees surrounding the water courses, but as the population density has increased this area has been deforested (Wamalwa 2013). The deforestation together with encroachment by agriculture to the river banks, chemical pollution and planting of Eucalyptus along the river, has contributed to decreased water quality and quantity in the river (Musikoyo 2013; Wamalwa 2013).

3. Background

3.1 Agroforestry

Agroforestry combines agriculture and forestry in a system (Xu et al. 2013). Woody-perennials and crops are integrated in time, by a cropping sequence, or in space (Lundgren 1982). It is in fact an old practice that has received a name in later years (Nair 1993). Agroforestry as a broad discipline can be defined as: ***The integration of trees in farming systems and their management in rural landscapes to enhance productivity, profitability, diversity and ecosystem sustainability*** (Xu et al. 2013).

Agroforestry practices improve the long-term conditions of the soil which is both ecologically and economically important (Haldin et al. 2000). It decreases erosion, improves nutrient cycling, increases soil organic matter and microbial populations, and improves the water-use efficiency (Young 1989; Ashton et al. 2010). Further is the dependency of chemical fertilizers decreased, which are both difficult for many farmers to afford, and creates a long-lasting dependency because it only improves the soil in a short-term way (Haldin et al. 2000).

The interaction between crops and trees does also have socioeconomic benefits (Gama-Rodrigues 2011). The food security is increased since agroforestry decreases the dependency on one specific crop which reduces the exposure to seasonal and environmental variations (Haldin et al. 2000). The tree component itself has several functions and can for example be used for timber, medicine and fodder (Xu et al. 2013).

3.2 Tree functionality

Different agroforestry species have either a single or multiple functions, with multipurpose trees being most common on small-scale farms (Tingsabadh et al. 1994). One example is Avocado *(Persea Americana)* that is mainly planted to get fruits, but also gives firewood and has medicinal values (Appendix II). Multi-functional trees reduce the risk of total crop failure since for example the wood still can be used if all the leaves are killed by a pest (Tingsabadh et al. 1994). It is also advantageous because a small farm has many needs and limited space (Biggelaar 1996). The income from trees is necessary for small-scale farmers to be able to pay school fees, clothes, food and household goods (Makhoka 2013). It is usually the man in the family that decides what trees that should be planted but the woman can decide over trees that give firewood and food (Makhoka 2013).

Even if agroforestry trees have different advantages such as reducing soil erosion and improving the fertility, farmers usually plant trees to harvest the outputs directly such as fruits, firewood, medicines, and timber (Biggelaar 1996). Agroforestry trees can be separated into categories based on their main functionality. When the tree is harvested it is usually used for its original purpose even if there also can be additional uses (Biggelaar 1996). Firewood trees, fruit trees, and fodder trees are important agroforestry groups and trees are also often planted for getting fiber (Nair 1993). In this study trees with ornamental, cultural, and medicinal values were also found. If the tree has a cultural value, it is often protected and cannot be used for e.g. firewood or fiber.

3.2.1 Fiber

Fiber trees in this thesis refer to trees that commonly are used for building materials, poles, and furniture due to their structure. Important characteristics of fiber trees are that they are fast-growing and produce fewer and smaller branches (Tingsabadh et al. 1994). The wood should be hard and have long fibers (Tingsabadh et al. 1994). The other important characteristics are dependent on the intended function. It is typically important that the wood is termite resistant, but if it is aimed to be used for poles it is also crucial that the stems grow straight and do not have knots since it reduces the strength (Fig. 4) (Tingsabadh et al. 1994).

Eucalyptus *(Eucalyptus)* is a popular fiber tree among small-scale farmers in Kenya since it is has a high growth rate (Ong 2003). However, it is also known that it is competitive with the crops and has several properties that influence the environment negatively (Ong 2003). It consumes a lot of water, causes erosion, and has a negative impact on soil properties and nutrient cycling (Ong 2003). Due to these disadvantages Eucalyptus is not seen as an agroforestry tree and thus not promoted by Vi Agroforestry (Makokha 2013). An alternative that has been popular in East Africa is *Grevillea robusta* (Ong et al. 2006). This tree is also problematic though, since it is an evergreen and requires lots of water. Another disadvantage with Grevillea is that it has a lateral root system that exploits the same soil horizon as the crops and hence is very competitive for nutrients even though it is nitrogen fixing (Ong et al. 2006).

Nine different trees species with fiber as the main function were found in the study area in Hututu. These were; *Cordia africana*, *Croton macrostachyus*, *Croton megalocarpus*, Cypress *(Cupressus)*, Elgon teak *(Olea capensis)*, Eucalyptus, *Grevillea robusta*, *Markhamia lutea*, and *Prunus africana*.

Figure 4: Straight fiber poles without knots are transported away from Hututu.
Photo: Sabina Berntsson

3.2.2 Firewood

Firewood is in this thesis defined as unprocessed wood that is suitable to use as fuel for cooking, heating, and sometimes lighting. Firewood species are characterized as fast growing, require minimum work effort, retain as many shoots as possible, and widely branched (Tingsabadh et al. 1994). Firewood trees often have other functions and it is common that the branches of the tree are used for firewood and the trunk for timber (Tingsabadh et al. 1994). The branches of the tree should not have thorns and be thin enough to be cut with hand tools (Tingsabadh et al. 1994). To give a good fire the wood should be dense, have low moisture content, and produce minimal and nontoxic smoke (Tingsabadh et al. 1994). In reality, fuel can be attained from any woody material and therefore all woody species can be used for firewood purposes (Fig. 5).

Figure 5: Any woody material can be used as firewood in Kenya.
Photo: Sabina Berntsson

Woodfuel that is both firewood and charcoal, is the main energy source in rural communities and accounts for 68% of the total primary energy consumption in Kenya (Ministry of Energy 2004). Studies done by Akinga (1980) and the Ministry of Energy (2002) show that there is a growing gap between the supply and demand in woodfuel. In the study from 2002 it was estimated that Kenya has a sustainable woodfuel production of 15 million metric tons per year and a demand of 35 million metric tons. The gap was filled through stock depletion and use of crop residuals (Ministry of Energy 2004). By the year 2020 the deficit is estimated to increase to 33 million metric tons (Ministry of Energy 2004). The deficit in firewood contributes to the ongoing forest degradation in Kenya (Mathu 2011). In the past firewood used to be collected from public woodlands close to the villages but due to the rapid decrease of these, farmers are forced to use crop residuals or steal wood from privately owned land instead (Haldin et al. 2000). Through the new forest policy in 2005 there is a general ban to collect firewood from common areas (NEMA 2009).

In Trans Nzoia almost 75% of households get their firewood from their own farms (Haldin et al. 2000). According to the information obtained from the interview with Makokha (2013) is access to firewood general problem in Trans Nzoia but nevertheless is trees generally not planted for this purpose. Instead farmers rely on wood left over from timber trees that have been cut down, branches from shrubs, crop residues and contribution from neighbors (Makokha 2013).

Figure 6: A Sesbania with harvested trunks. A new tree is about to regenerate.
Photo: Sabina Berntsson

Bredelia micrantha and *Sesbania sesban* (Fig. 6) were the only tree species found in the study area that mainly were grown for firewood purposes.

3.2.3 Fodder

Fodder trees are trees that provide food for livestock. The leaves and pods are used to feed the animals while the rest of the tree is often used in other purposes (Tingsabadh et al. 1994). The trees should be fast growing and good at regeneration just as firewood trees, and the branches of the fodder trees are commonly used for firewood (Tingsabadh et al. 1994).

Trees with fodder functionality usually fixate nitrogen, both to enhance the soil fertility and to get protein rich fodder (Tingsabadh et al. 1994). When animals are given fodder on the farm, their milk production increases (Pye-Smith 2010) and the availability of milk is improved (Haldin et al. 2000).

No trees with fodder as main function were found in the study area of Hututu. But the class is still included in the analysis since fodder often is the secondary product of trees. Fodder can also be obtained from shrubs, hedges, and crops residues (Kirungu et al. 2002).

3.2.4 Fruit

In this thesis the term fruit trees are trees that bear fruit used for human consumption. The most important factors that influence the planting of fruit species are local taste and market patterns (Tingsabadh et al. 1994). Production of fruits helps to diversify the food and add important nutrients to the diet (Haldin et al. 2000).

Firewood is often collected from fruit trees as an additional output but if they are pruned too often it disturbs the flower production and therefore reduces the amount of fruits (Tingsabadh et al. 1994). Firewood can instead be collected from fallen branches (Tingsabadh et al. 1994).

Avocado (*Persea americana*), Guava *(Psidium guajava)*, Loquat *(Eriobotrya japonica)*, Mango *(Mangifera indica)*, Syzygium *(Syzygium)* and White Sapote *(Casimiroa edulis)* are the fruit species found in the study area in Hututu.

3.3 Crops

Maize is staple food in Kenya and the food culture is to eat it marched into a stiff polenta like porridge, ugali (Fig. 7), or boiled together with beans, githeri (O´Callaghan et al. 1994; De Groote and Chege Kimenju 2012). In small-scale farms is it common to plant the maize together with a short-term crop and in Trans Nzoia intercropping with maize and beans is very common (O´Callaghan et al. 1994). All over Kenya intercropping in general is a very common practice at small- to medium-scale farms (O´Callaghan et al. 1994). There are several reasons for this and some examples include; land pressure, risk spreading against natural hazards, higher returns on the same land, and advantages in having crops that mature early to bridge the food gap between the two harvest seasons (O´Callaghan et al. 1994).

Figure 7: The staple food ugali, here served with Sukuma wiki (made from Kale). *Photo: Sabina Berntsson.*

There are also disadvantages however. The study made by O´Callaghan and others (1994) showed that beans that are intercropped with maize in Trans Nzoia only can have 66% cover compared to beans-only plantations. In the study they also found a decrease in bean yields during intercropping that varied between 12.5% (in 1988) and 33% (in 1990 and 1992) due to shading of the crop. Further, competition for water is a potential source for maize yields reductions in Kitale, especially during dryer years. Other problems with intercropping that were mentioned in the article are technical problems during planting, different timing requirements for fertilizer spreading, and competition for light and nutrients between the crops. Even though these problems occur, O´Callaghan et al. 1994, found that the overall effects of intercropping only was minimal for the yields of each crop, and even is positive for the total production. Instead, the main drawback that limits intercropping is the use of machines in farming. However, this is not a problem on the small- to medium-sized farms in Kenya where intercropping is common.

Figure 8: Intercropping of Maize and Beans. *Photo: Simon Hallberg*

Different types of crops have different water demands. The water needs for the nine crops that were found in the area (Maize, Beans, Sugarcane *(Saccarum)*, Irish potato, Kale (*Brassica oleracea* var. *acephala*), Millet, Napier grass (*Pennisetum purpureum*), Sweet potato, and Banana *(Musa)*is presented as optimal and absolute annual rainfall in Table 1.

Table 1: Crop water needs for the crops that occurred in the study area. Presented as both optimal and absolute yearly precipitation and sorted from highest to lowest minimum optimal rainfall.

Crop water needs (mm prec./yr)		
	Optimal	**Absolute**
Banana	2400-2700	2000-3500
Napier grass	1500-2500	850-4000
Sugarcane	1500-2000	1000-5000
Sweet potato	750-2000	350-5000
Maize	600-1200	400-1800
Beans	500-2000	300-4300
Millet	500-1100	300-4300
Irish potato	500-800	250-2000
Kale	450-1000	300-2800

Maize

Maize is an annual crop used worldwide, both as human food and as animal fodder and is one of the most important cereals (FAO 2013 a.). There are several varieties adapted to different climates (FAO 2013 a.). The optimal annual rainfall for maize ranges between 600-1200mm with an absolute rainfall need of 400-1800mm (FAO 2007 g.). To gain good yields it is important to choose a variety that has a growing period that matches the growing seasons in the area (FAO 2013 a.).

In Kenya, maize is the most common food crop (Muthoni and Nyamongo 2009). According to a study made by Cooper and Law in Kenya 1978, the variety commonly used in Trans Nzoia requires 1680 GDD[7] to mature.

Beans

Beans can grow in areas with varied climate conditions. The need for annual rainfall rages between 500-2000mm, with an absolute interval of 300-4300mm (FAO 2007 f.). However, beans are sensitive to hail which can cause defoliation of the crop and kill it (FAO 2007 e.). When beans are intercropped with maize this problem is reduced since maize grow taller and protects the ground cover of beans (O´Callaghan et al. 1994). Hail storms are frequent in Trans Nzoia and according to a study made by O´Callaghan and others (1994), protection of the beans is the main reason to why maize and beans commonly are planted together in the County. Another benefit with beans in intercropping is that beans fixate nitrogen which reduces the need of fertilizer application (FAO 2013 c.).

Bean is an annual crop and has a growing season of 780GDD and is hence harvested during the rainy season in Trans Nzoia (Cooper and Law 1978). Nevertheless, beans are influenced by the amount of precipitation since it often is affected by diseases when the soil becomes too wet due to heavy rain or poor soil drainage (FAO 2007 e.). To avoid soil-borne diseases, the crop is commonly planted in rotation with maize, sweet potato or cotton in Tropical Africa (FAO 2013 c.).

Sugarcane

There are several types of Sugarcane that is a perennial crop belonging to the genus *Saccarum* (FAO 2013 b). Almost all production of sugarcane in Kenya (about 90%) comes from small-scale farms (Odenya et al. n.d.). The growth of sugarcane is directly proportional to transpiration of water and therefore it is important that the crop has enough water throughout the growing period (FAO 2013 b). How much it needs is dependent on the climate and the range of annual rainfall for growth is1000-5000mm with an optimum of 1500-2000 mm (Brouwer and Heibloem 1986; FAO 2007 h.). This can be compared to maize which is more efficient in water usage and have an optimal interval of annual rainfall of 600-1200 mm depending on the climate (Table 1) (FAO 2007 g.). The production in Kenya is largely dependent on rainfall, but since rain is an unreliable factor more irrigated plantations would improve the yields (Muturi and Wawire 2006). Waterlogging is also not good and the soil should preferably be moist but well aerated (FAO 2013 b).

[7] For definition see Appendix I

Irish potato

Irish potato is the second largest food crop in Kenya after maize (Muthoni and Nyamongo 2009). It is mostly produced by small-scale farmers in rain fed agriculture in the cool highlands (1500-3000 m.a.s.l.) (Muthoni and Nyamongo 2009). It has a growing period of 3-4 months in these areas which makes it possible to have three harvests during one year instead of maize which needs up to 10 months to mature (Muthoni and Nyamongo 2009).

The harvests of potatoes in Kenya are generally small (Muthoni and Nyamongo 2009). Partly due to poor soil fertility in the areas where they are planted and bad seed quality, but also since the farmers put their efforts on other crops such as maize, beans, tea and coffee and do not apply enough fertilizers, herbicides, and pesticides (Muthoni and Nyamongo 2009). To be able to maintain soil fertility, crop rotation with for example potatoes, maize, and beans is often practiced (FAO 2013 e). In areas with less rainfall are Irish potatoes commonly planted together with beans during the shorter rains when the amount of water is too sparse to maintain maize crops that are more water dependent (Muthoni and Nyamongo 2009).

Irish potato is an annual crop and requires 250-2000mm rainfall per year and has an optimal interval of 500-800mm (Table 1) (FAO 2007 i). It grows well in well-drained soil with a lot of air pours (FAO 2013 e). However, it is relatively sensitive to deficits in water and optimum yield requires more than 30-50 percent of the available soil water (FAO 2013 e). In some limited parts of Kenya irrigated potatoes are produced off-season (Muthoni and Nyamongo 2009).

Kale

Kale is a biennial to perennial crop that is member of the cabbage family (FAO 2007 b). It is a non-headed cabbage that grows on a stem that can grow up to 1 meter high (Fig. 9) (FAO 2007 a). It is usually planted on small-scale fields (FAO 2007 b). Both the stem and the leaves can be eaten or fed to the livestock (FAO 2007 a). Annual rainfall of 450-1000 mm is optimal depending on the temperature (Table 1) but it can survive with precipitation between 300 and 2800 mm (FAO 2007 b). Optimal yields are obtained if the crop is planted and irrigated during the dry season (FAO 2007 a). It has a growing season of 60-85 days (FAO 2007 a).

Figure 9: Kale planted next to River Nzoia, Hututu settlement. *Photo: Josefin Winberg*

Millet

Millet is several different types of small-seeded annual grasses that are cultivated as grain crops

(ICRISAT 1996). Finger millet is the one of the most important cereal crops in Kenya's North Rift Valley province where Trans Nzoia is a part (Kute et al. 2000). The grain is used as human food and the straw can be used as green fodder or hay (FAO 2007 c). It is mostly cultivated in small fields that are less than 2023.4 m^2 (0.5 ac) in size at small-scale farms (Kute et al. 2000). Just as all millet types, Finger millet is better adapted to dry climates and infertile soils than other crops and is therefore often planted in areas with extremely bad growing conditions (ICRISAT 1996). The optimal rainfall ranges between 500-1100 mm yr^{-1} (Table 1) but it can survive in conditions of 300-4300 mm annually (FAO 2007 d).

Napier grass

Napier grass also known as "elephant grass", has become the main food source for livestock in the most productive parts of Kenya (Orodho 2006). The increasing population in these areas has decreased average farm sizes and to gain space animals are fed directly instead of being pastured (Orodho 2006). Napier grass is a high-growing perennial bunchgrass that is cut to get fodder and since it is good at regeneration it can be cut in 6-8 week intervals depending on the weather and the fertilizer application (Fig. 10) (Orodho 2006). It can be grown together with legumes but in Kenya it is commonly grown in pure stands, often in hedges, and sometimes together with trees such as Sesbania or Calliandra (Fig. 11) (Orodho 2006).

Figure 10: Napier grass. *Photo: Sabina Berntsson*

Figure 11: Napier grass growing as a hedge between fields of intercropped Maize and Beans *Photo: Simon Hallberg*

To gain optimal yield Napier grass requires high amounts of precipitation throughout the season Orodho 2006). The optimal annual precipitation is between 1500-2500mm and it has a limiting interval for growth of 850-4000mm yr^{-1} (FAO 2007 k). The deep-going root system makes it resistant to droughts and it can withstand 3-4 months without rainfall (Orodho 2006). However, it is sensitive to flooding and waterlogging. The vigorous root system also makes it good for erosion control and it is often planted on the edge of terraces (Orodho 2006).

Sweet potato

Sweet potatoes can be cultivated in different agro ecological zones and the crop can survive in conditions with a yearly precipitation that ranges from 350-5000mm (KARI n.d. a; FAO 2007 l). The optimal growth however, occurs when the rainfall is between 750-2000mm (FAO 2007 l). Sweet potatoes is an annual crop and have a growing period of 3-6 months depending on the species, and the farmers usually prefer the ones that mature late during the long rains and the faster one during the short rains (KARI n.d. a). In areas around Kitale are sweet potatoes sometimes intercropped with maize after the intercropped beans have been harvested (KARI n.d. b). Sweet potatoes can be cultivated on relatively nutrient-poor soils and fertilizers are commonly not applied (KARI n.d. b). For good root development they need well-drained and porous soil (KARI n.d. a). Soils with a lot of stones should be avoided since they limit the growth of the tubers (KARI n.d. b).

The crop is protein rich (10-15%) and is therefore good for fodder (KARI n.d. b). It is cut in small pieces and mixed with Napier grass or maize stover and then fed to the livestock in a proportion of 20-50% sweet potato (KARI n.d. b). It is also common to use the terminal shoots or vines for animal food to save the storage roots for the humans (Gomes and Carr 2003).

Banana

Bananas can be eaten in two different stages. When the banana is ripe it is sugary and eaten raw (FAO 2013 d). The unripe bananas are called plantains and must be cooked before being eaten (FAO 2013 d). It is a perennial crop and the plant has an average life of 4-6 years (Fig. 12) (FAO 2013 d). It is highly water dependent and requires frequent water supply throughout the crop season (FAO 2013 d). The rainfall need for optimal growth is 2400-2700 mm per year and the range for growth is 2000-3500mm/yr (Table 1) (FAO 2007 j).The bananas are often planted in dug holes both to collect water and to improve the soil fertility by mulching material that is placed in the hole and decomposed (Fig. 13) (FAO 1977).

Figure 12: Banana stem with a banana flower. *Photo: Simon Hallberg*

Figure 13: Banana trees planted in manmade planting holes. *Photo: Sabina Berntsson*

4. Theoretical background

4.1 Remote sensing

Remote sensing is defined as obtaining information about an object, area or phenomenon from a distance, or by using a device that is not in physical contact with the object (Lillesand et al. 2008). Data for remote sensing are commonly photographs obtained by airplane or satellites. This photogrammetric data are used to survey the planet, and are often used in meteorology, mapping (Fig. 14), and studies of land cover and vegetation changes (Harrie 2008).

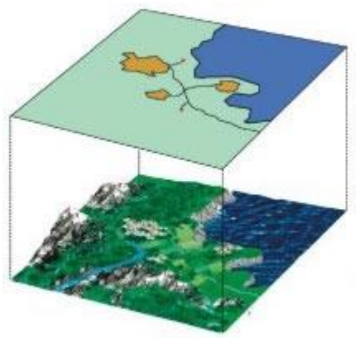

Figure 14: Map creation from remote sensing and GIS. Source: GIS centre, n.d.

Remotely-sensed data never describe the reality perfectly. There are many sources of error that influence the result i.e. aircraft movement, lens distortions, clouds, and shadows. Errors can also surface during the data analyzing process (Congalton and Green 2008). The accuracy of remotely sensed data is important to determine to get information about it and be able to rely on the modeled data, especially if it is supposed to be used in a decision-making process (Congalton and Green 2008). This is done by comparing the interpreted data with observations in field.

4.2 Ground truth

In remote sensing "ground truth" as a term stands for near-surface observations (Short 2006). Ground truth comprises the gathering of information about states, conditions, and parameters on-site, and the usage of the data as reference information, i.e. for accuracy evaluation of digitized maps (Short 2006).

4.3 Accuracy assessment

Accuracy assessments measure the quality of a remotely-sensed map by isolating the errors. There are two types of measurements that can be used to determine the map accuracy, positional and thematic accuracy. Positional accuracy compares the location of a map feature to its real location collected from the reference data. Thematic accuracy deals with the classification and attributes to a mapped feature and controls if it differs from the true feature label (Congalton and Green 2008). In this report we have focused on evaluation of the thematic accuracy.

The accuracy of a map can be computed in several ways by using different methods. To obtain a complete evaluation several methods should be processed and analyzed for the same map (Lillesand et al. 2008). When the accuracy is determined errors can be found and corrected (Congalton and Green 2008). It is important to remember though, that the accuracy of the reference data is not always perfect. It can be influenced by factors such as misregistration, data entry errors and changes in land cover due to different dates of interpretation data gathering and the reference data collection (Lillesand el al. 2008).

4.3.1 Error matrix

An error matrix is the most common method to present the thematic accuracy (Congalton and Green 2008). It consists of a square table where the rows represent the map data and the columns the reference data (Table 2). The reference data are sites that were controlled on the ground (ground truth) whereas the map data are predicted classifications (Lillesand et al. 2008). In an error matrix the relationship between the two data sets is evaluated, category-by-category (Lillesand et al. 2008).

Table 2: Error matrix for two land cover classes, Annual crops and Perennial crops. The columns are reference data and the rows are the mapped values obtained from remote sensing. The light grey boxes show the number of correctly classified points and the lower right corner (dark grey) gives the total number of evaluated points

Classification	Annual crops	Perennial crops	**Row Total**
Annual crops	70	1	71
Perennial crops	2	2	4
Column Total	72	3	**75**

Two types of errors are expressed with the error matrix, omission errors (exclusions) and commission errors (inclusions) (Lillesand et al. 2008). Omission errors are defined as omitting an area from a class where it belongs, and commission errors as including an area in the wrong category. An error on a map is thereby actually an omission and a commission error on the same time but to different categories (Congalton and Green 2008). By studying the error matrix it can be determined if there is a general confusion between some classification categories, i.e. trees and woodland.

4.3.2 Overall accuracy, User´s and Producer´s accuracy

Besides omission and commission errors there are several other measurements that can be obtained from an error matrix. Overall accuracy is a measure of total accuracy of the map and is collected by dividing the number of correctly mapped reference locations with the total number of sample units (Congalton and Green 2008). The total number of correctly mapped locations is determined by summing the diagonal of the error matrix (Congalton and Green 2008). Since it just represents the diagonal, overall accuracy does not include errors of omission or commission (Lillesand et al. 2008).

User´s and Producer’s accuracy visualize the accuracy of each class instead of just a total accuracy of the map (Congalton and Green 2008). Even if the accuracy of the whole map (overall accuracy) is poor, the map can still be adequate if the primary propose is to locate a specific category (Lillesand et al. 2008). User’s and Producer’s accuracy are good to use for this.

User’s accuracy

User´s accuracy describes the probability of ending up in the right class when you try to visit a specific class in the field, e.g. the chance that you will arrive in a field planted with the annual crop that matches the label in the map (Congalton and Green 2008). It is calculated by dividing the number of correctly classified reference locations in each category by the total number of reference locations in the class (see example below). User´s accuracy is represented by the correctly classed data on the major diagonal divided by the row total in the error matrix (Table 2) (Lillesand et al. 2008).

Producer’s accuracy

A high Producer´s accuracy on the other hand indicates that there is a higher probability that annual crop is correctly classified and that you will cover all fields with annual crop in the map area if you visit all the labeled locations. (Congalton and Green 2008). Producer´s accuracy is calculated by dividing all the correctly classified reference locations in each category by the number of reference locations that belongs in that class according to the map (see example below). This is achieved by dividing the correctly classed data from the diagonal with the column total (Table 2).

Example of how user’s and producer’s accuracy are calculated, based on the error matrix in Table 2.

User´s Accuracy:	**Producer´s Accuracy:**
Annual crops = 70/71 = 98.6%	Annual crops = 70/72 = 97.2%
Perennial crops = 2/4 = 50.0%	Perennial crop = 2/3 = 66.7%

Kappa coefficient

A way to measure how well the classification performed by remote sensing agrees with the reference data is Cohen’s kappa (“KHAT” analysis) (Congalton and Green 2008). Even if the interpreting classification was done completely without any knowledge or by random assignment there is a possibility that some points would be correctly categorized just by chance (Lillesand et al. 2008). The Kappa coefficient is an indicator of how much better the map is than chance. It is a statistical test of the difference between actual agreement between the reference data and an automated classifier and the chance agreement between the two (Lillesand et al. 2008) and can be defined as follows:

$$\hat{k} = \frac{\text{observed accuracy} - \text{chance agreement}}{1 - \text{chance agreement}}$$

The Kappa statistic is an indicator of how many of the correctly classified categories that are due to “true” agreement and how many that instead are due to “chance” (Lillesand et al. 2008). The Kappa coefficient ranges between 0-1 where 1 represents the ideal case of 100 percent agreement whereas 0 represents a classification that was completely due to chance (Lillesand et al. 2008).

The Kappa equation is based on the error matrix (Table 2). The observed accuracy is represented by the sum of the cells where the row coincides with the column and is the major diagonal in an Error matrix. The chance agreement is indicated by the row and the column totals (Congalton and Green 2008).

The equation of Kappa is written as follows:

$$\hat{k} = \frac{N\sum_{i=1}^{r} x_{ii} - \sum_{i=1}^{r}(x_{i+} * x_{+i})}{N^2 - \sum_{i=1}^{r}(x_{i+} * x_{+i})}$$

Where: r = number of rows in the error matrix

x_{ii} = number of observations in row *i* and column *i* (on the major diagonal)

x_{i+} = total number of observations in row *i* (shown as marginal total to the right of the matrix)

x_{+i} = total number of observations in column *i* (shown as marginal total at bottom of the matrix)

N = total number of observation included in the matrix

Example from the error matrix above:

$$\sum_{i=1}^{r} x_{ii} = 70 + 2 = 72 \qquad \sum_{i=1}^{r}(x_i * x_{+i}) = (71 * 72) + (4 * 3) = 5124$$

$$\hat{k} = \frac{75(72) - 5124}{75^2 - 5124} = 0.55$$

5. Data

The premade land cover map material were digitized from Orthoready Standard QuickBird imageries with 0.60 m spatial resolution and covered the settlements Botwa, Hututu, Sinoko, Wehoya, and Yuya. The satellite images were taken in August and October 2010, and April and December 2011. The land cover maps were manually digitized in 2012 by ICRAF, Nairobi, based on a classification key (Appendix III) and the resulting maps can be seen in Appendix IV. The datum of the images is WGS84 and the projected coordinate system is Universal Transverse Mercator, UTM zone 36N.

5.1 Data collection

The coordinate locations for the map accuracy evaluation where sampled using a GPS (Magellan Explorist 610). The GPS settings during the sampling were WGS84 with primary coordinate system lat/long, and the primary coordinate accuracy was set to 10 meters. During the sampling the accuracy varied between 4 and 11 meters.

6. Method

In short the study can be described as separated into two main parts. The first part consists of an evaluation of existing map material with purpose to get as reliable data as possible for the relationship analysis. Based on this evaluation, a study area was selected in one of the settlements.

Secondly, a more detailed land cover map, a tree functionality map and a tree species map was created through extensive field work. These maps were later used to evaluate the relationship between water proximity and land cover patterns.

6.1 Evaluation of land cover maps

The land cover maps over the five settlements, Wehoya, Yuya, Botwa, Hututu, and Sinoko (Fig. 2) was evaluated by comparing the mapped classification of known locations with field collected land cover data. For this, existing land cover in selected ground truth points was gathered in April 2013.

6.1.2 Road sampling

The ground truth data was mainly sampled through road sampling (Persson 2012). Data was collected along selected roads that cover the whole settlement. The roads were selected through studies of the land cover maps to get a high diversity in the samples and to cover as many land cover classes and parts of the study area as possible. In an interval of 200 meters one GPS point was taken and four land cover data points were sampled. Two points on each side of the road were identified on distance, 1 meter from the road and 10 meter from the road. The collection was made from the car. If the road was situated on the border of the settlement, points were only collected inside the settlement. The land cover in each point was classified according to the same classification key that had been used for the interpretation of the satellite images and it can be seen in Appendix III.

The number of data points collected in each area is dependent on the road quality and number of existing roads. A minimum number of road sampled data points for each area were set to 20 points per km^2. The selected roads in each area were chosen by considering diversity of land cover along the road as well as the road connectivity and distribution over the whole area. The number of points collected in each settlement varied with size of the settlement and ranged from 172 points in Yuya, 198 in Botwa, 200 in Hututu, 206 in Sinoko and 253 in Wehoya.

6.1.3 Selective point sampling

Selective point sampling was done for each settlement as a complement to the road sampling since some land cover classes were not represented in it. Transects were created for each area and along these points were collected in pre-selected land cover classes. The land cover classes that were under-represented were identified through the results of the road sampling. Classes with no or very low representation were selected for additional sampling. A GPS was used to sample the coordinate of the points, and the land cover for these locations was noted.

6.1.4 Data management

The spatial data were managed and analyzed using a geographical information system (ArcGIS 10.0). The coordinates collected from the road sampling and the selective point sampling were inserted to the program and represented as points. When the road sampling coordinates did not correspond to roads on the land cover maps, the points were manually shifted at a 90 degree angle towards the road.

For each road sampling coordinate, two new points were created on each side of the road representing the ground truth points. These points were added at 1 and 10 meter distances from the roads, and they were placed by creating polygons with widths of 1 and 10 meters around each side of the road (Fig. 15). The new points were then manually added at the outer border of these polygons at 90 degree angles from the road sampled coordinates, or in some cases the coordinates that had been moved to the center of the road. Coordinates for the added points were later calculated in the GIS software.

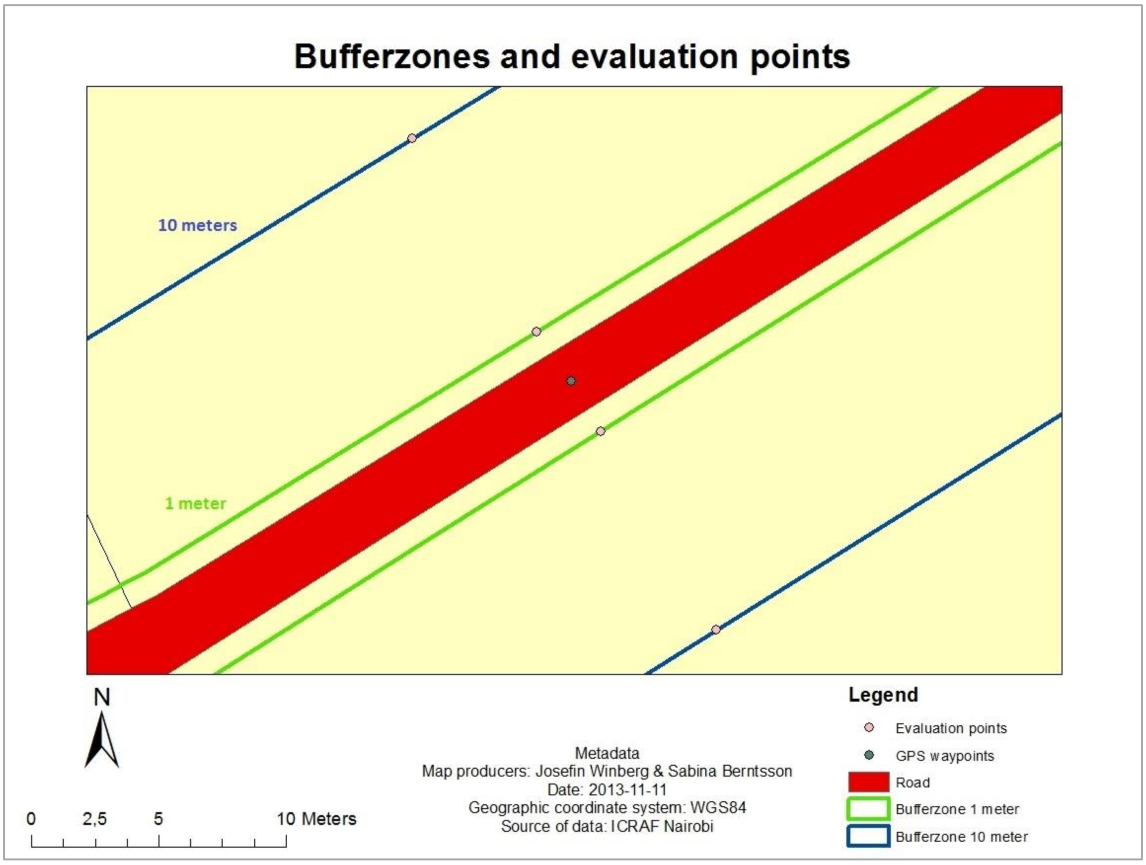

Figure 15: Working process to create evaluation points on 1 meter and 10 meters from the road. The point in the middle of the road is the GPS points and the two points on each side of the road represent the manually created evaluation points.

6.1.5 Accuracy evaluation

The land cover maps over the five settlements (Botwa, Hututu, Sinoko, Wehoya, and Yuya) were evaluated for thematic accuracy by comparing field data with mapped land covers of the same locations. The comparison was done in ArcGIS by using an overlay function that gave the classified ground truth points a second attribute copied from the mapped land cover at coinciding coordinates. The mapped land cover and the field data was later inserted into Excel for accuracy calculation. An error matrix was created and overall accuracy, user's accuracy, producer's accuracy and Kappa estimation were calculated using the equations that are described in the theoretical background above.

6.2 Evaluation of water proximity and land cover patterns

After the evaluation of the accuracy of the existed land cover maps, it was decided that an improved land cover map was needed to be able to investigate the relationship between water proximity and crops grown. Since it would have been too time consuming to do this for all settlements or even one whole settlement, a study area in one of the settlement was created. Through the accuracy evaluation of the land cover maps Hututu was detected to be the settlement with the most accurate map and a study area was therefore selected in this settlement. The study area consisted of two physically separated parts that together covered the two watercourses that occurred in the settlement.

6.2.1 Detailed land cover map

The improved land cover map has a more specified classification which covers crops and trees on species level. It is here called a "detailed land cover map". This map was made based on the evaluated land cover map over Hututu settlement and extensive field work covering the whole study area. The land cover of all polygons was physically checked from near distance and classified on species level with help from an advisor with good knowledge about local crops, trees and agriculture. In some rare cases the species were not identified and the polygon was instead classified with crop or tree type as highest level.

The polygon layer from the evaluated land cover map was used as a frame for creating the detailed land cover map, but polygons were split, added, and reclassified to obtain a representative map. The categories annual crops, perennial crops, trees, woodland, and hedge were updated and assigned with new more detailed classifications on species level. To be able to make maps that are easy to interpret the detailed land cover map focused on the agricultural crops grown. The number of attributes from the dataset of tree species was large which made the detailed land cover map messy and hard to interpret. Therefore, attributes from the detailed land cover maps was excluded in the map presented in this report to avoid misinterpretations. However, the data set was still tested and used in the relationship test.

6.2.2 Tree functionality maps

A tree functionality map was made based on the tree species information from the detailed land cover mapping. The tree species were categorized into tree functionality classes based on the main functionality of the tree. The information needed to perform the classification was obtained from interviews and literature searching.

6.2.3 Test for relationship

The relationship between water proximity and land cover, tree species and tree functionality was investigated in ArcGIS. Firstly, the study area was separated into three different intervals; high influence of closeness to water courses, mediate influence and no influence. This was done by creating polygons representing 0-100, 100-200 and >200 meters distance on each side of the water courses with the buffer zone function in ArcGIS. The distances of the buffer zones were determined from field observations in the study area.

The total area of each land cover class, tree species and tree functionality within each interval was calculated. This was done by an overlay of the polygons representing the intervals and the relevant data sets. Since the buffer zones are of unequal area (>200 meter is larger), the prevalence of each crop or tree within the buffer zone have been normalized compared to the total area of studied species to understand how the species are distributed within the study area. A high percentage within the buffer zone close to the river indicates that the crop or tree could be more water-dependent and therefore is more prevalent near the water courses.

The relationship between proximity to buildings and land cover, tree species planted, and tree functionality was tested as an alternative factor that influences the land cover. The working process was the same as described for water proximity above. This time, buffer zones of 25 meters were created around each building in the study area (based on the average size of a homestead in Hututu settlement), and an overlay with land cover, tree species, and tree functionality was made. The total extent of each land cover class, tree species, and tree functionality category within the buffer zones was calculated, both as area in square meters and as proportion of the total class area in percentage.

6.3 Interviews

6.3.1 Information about the study area

To obtain information and understanding about the study area and water use in Hututu settlement two interviews were done. The persons interviewed were Mr. Robert Musikoyo, the Deputy Manager at Vi Agroforestry in Kitale, and Mr. Godfrey Wamalwa, one of the village elders in Hututu settlement. The interviews were carried out the 24 of April 2013 and the 26 of April 2013. The interviews were semi-structured (Bryman 2008) and the questions concerned historical land cover and water use in the area, tree cover changes, trees and tree functionality and changes in population density. During the interviews, notes were taken and a recorder used to be able to transcribe the information afterwards. Both interviews were held in English but for the interview with Mr. Wamalwa an interpreter was used to avoid misunderstandings.

6.3.2 Tree species characteristics

A third interview was performed the 14 of May with Mr. William Makokha, staff member at Vi Agroforestry in Kitale. During this interview no interpreter was used and the answers were not recorded. The interview was held by two persons and instead of recording, notes were taken by one person and the questions primarily asked by the other. This interview was semi-structured as well and did foremost concern the tree species that had been found in the area during field work even if some questions regarding the land cover and tree functionality in the settlements also were asked.

The questions about tree species concerned tree functionality, nutrient needs, water dependence, how the tree withstands water extremes, management, and prize of seedlings. This information was later summarized and can be found in Appendix II.

7. Results

7.1 Evaluation of land cover maps

The accuracy evaluation of the land cover maps is presented in Table 3 below and the error matrices are included in Appendix V. Overall accuracy for the five settlements ranges from 58.1% for Hututu, to 47.3% accuracy for Yuya. The Kappa statistics show that Wehoya, with a Kappa value of 0.331, is the map is only 33.1% better than chance. Hututu has the highest Kappa value of 0.459 that is 45.9% better than chance. Since Hututu had both highest Kappa value and highest overall accuracy it was chosen for detailed land cover studies.

Table 3: Overall accuracy, Kappa values and number of classes used in the evaluation of the five settlements (Appendix V).

	Botwa	**Hututu**	**Sinoko**	**Wehoya**	**Yuya**
Overall accuracy	57.3%	58.1%	51.1%	48.6%	47.3%
Kappa	0.437	0.459	0.364	0.331	0.336
Number of classes	19	19	16	20	17

Through the error matrices in Appendix V it can be seen that all land cover classes are not included in the accuracy assessment even though extra points were added during the selective point sampling. The classes that are not included are less frequently occurring (for example Shrubs), difficult to sample (Water, River and Water pond) or less interesting for a land cover study (i.e. Industry, Church and Cattle dip).

In Appendix V it can also be seen that there are land cover classes that have high user’s accuracy for most of the settlements but on the same time low producer’s accuracy. Producer’s accuracy for Hedge ranges between 13 to maximum 52 percent (Botwa 52%, Hututu 30%, Sinoko 18%, Wehoya 13%, Yuya 28%). However, user´s accuracy is almost always high and ranges between 74 and 92 percent for all settlement except Wehoya that has a user’s accuracy of 40%. This mean that what is mapped as Hedge on the digitized map also is hedge in the reality but some hedges are missed. The land cover class that hedges often are mapped as is Annual crop and Woodland.

The accuracy assessment of Homestead indicates that the land cover class has been difficult to interpret as well. Producer´s accuracy is low for all the settlements (Botwa 38%, Hututu 30%, Sinoko 46%, Yuya 21%, Wehoya, 49%) but user’s accuracy is high and ranges between 71 and 91 percent for all settlements expect Botwa that has a user’s accuracy of 56%. Homestead is often wrongly mapped as Annual crops.

Land cover classes that generally were difficult to map are Shrubland and Grassland. Both user´s and producer´s accuracy are low for these classes for the settlements where they were included in the evaluation (for Botwa, Hututu, Sinoko (only Grassland) and Wehoya). The number of evaluation points was few for these classes and most of them were added during the second evaluation process. No clear pattern of which classes that they have been confused with can be seen. Further is Perennial crops often wrongly classed and it is generally mixed up with Annual crops.

7.2 Detailed land cover and tree functionality

The detailed land cover maps, Figure 15 and 16, show agricultural crops grown in Hututu study area during April – May 2013. The land cover is similar in the two separated parts of the study area even if the northern part also is influenced by the large river at the eastern border. Intercropped Maize and Beans is the land cover class with by far largest extent and it is distributed all over the study area. This class is followed by Maize alone as the second most common. Shrubland mainly occurs close to the two rivers and Trees and Woodland are found here as well but also within and around the homesteads. Banana mostly occurs in small commands close to the homesteads.

The distribution of tree functionality in Hututu study area can be seen in Figure 18 and 19. The maps show the main functionality of the mapped trees and in addition to the important agroforestry groups mentioned in the introduction (Fiber, Firewood, Fodder, and Fruit) are trees with Cultural, Medicinal, Ornamental, and 'Ornamental, medicinal' as main function also found. There is also a class called Other that include one tree that could not be identified. The most common tree functionality is Fiber followed by Fruit and Firewood. No trees with Fodder as the main tree function were found in the study area during the field sampling. Almost all of the other classes occur all over the area, but Fruit mainly occur close to homesteads.

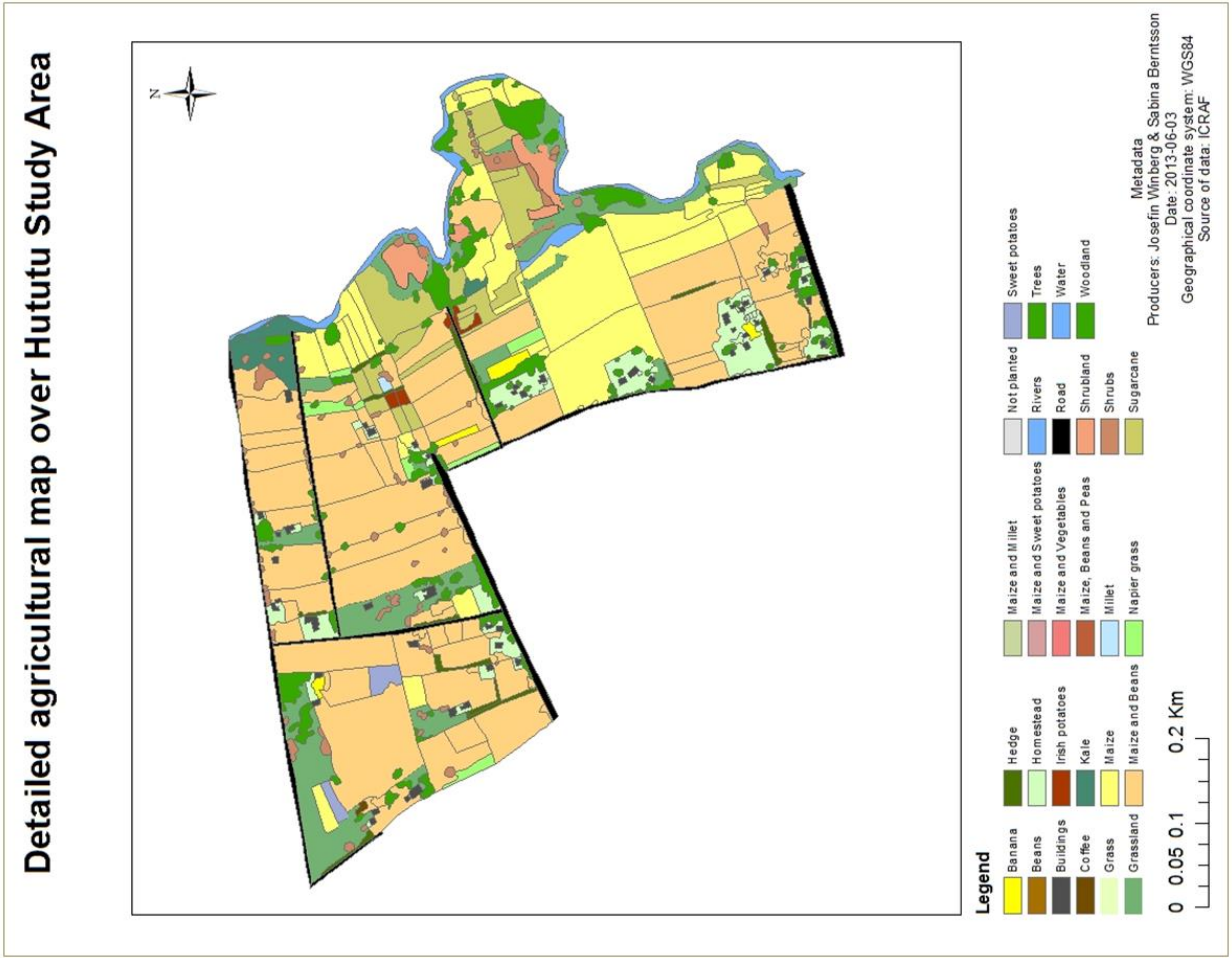

Figure 16: Detailed agricultural map over Hututu study area, Northern part. The classification is based on the main crops grown on the field during April-May 2013.

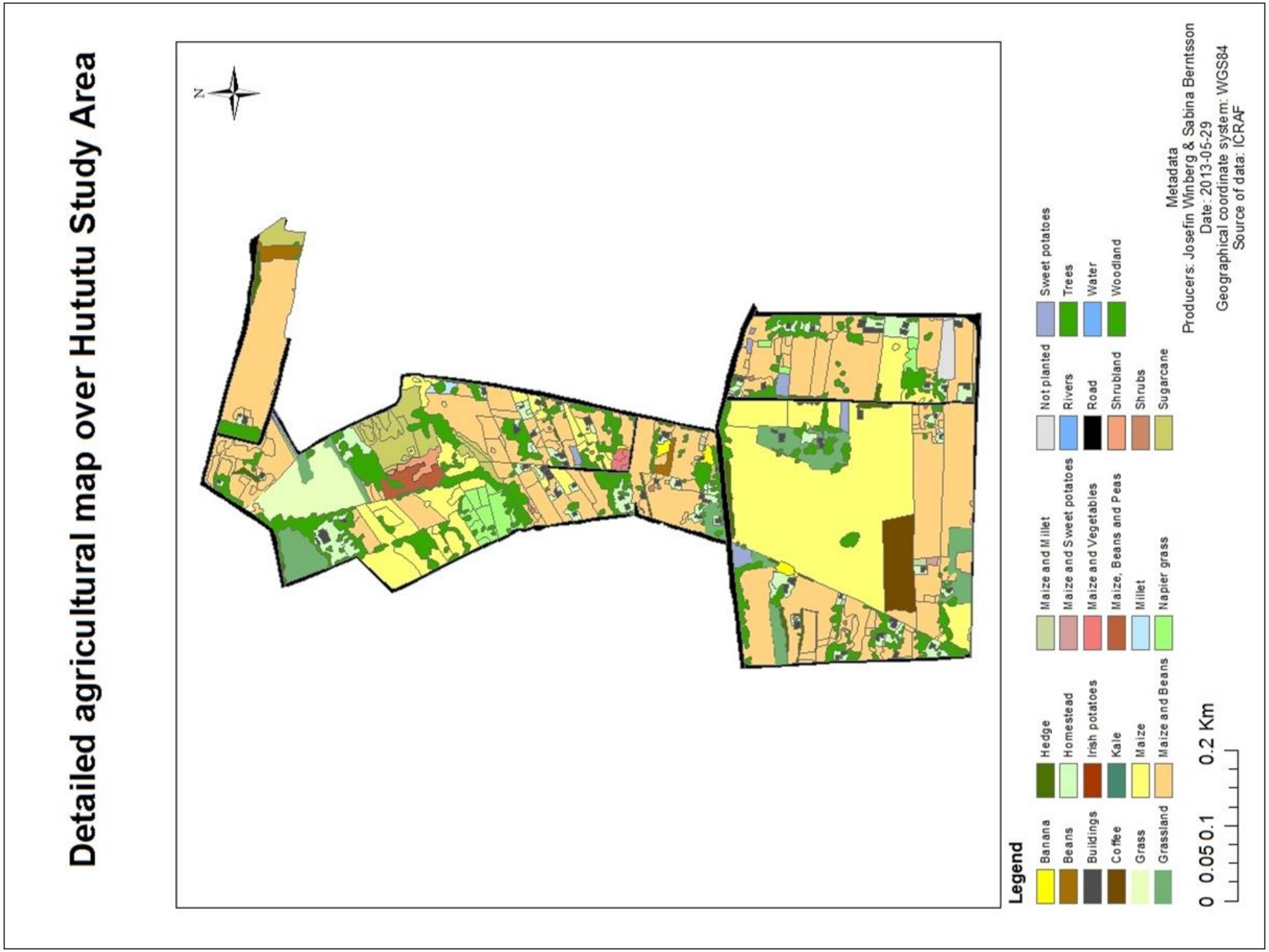

Figure 17: Detailed agricultural map over Hututu study area, Southern part. The classification is based on the main crops grown on the field during April-May 2013.

Figure 18: Tree functionality map over Hututu study area, Northern part. The trees are divided into classes based on their main functionality for farmers.

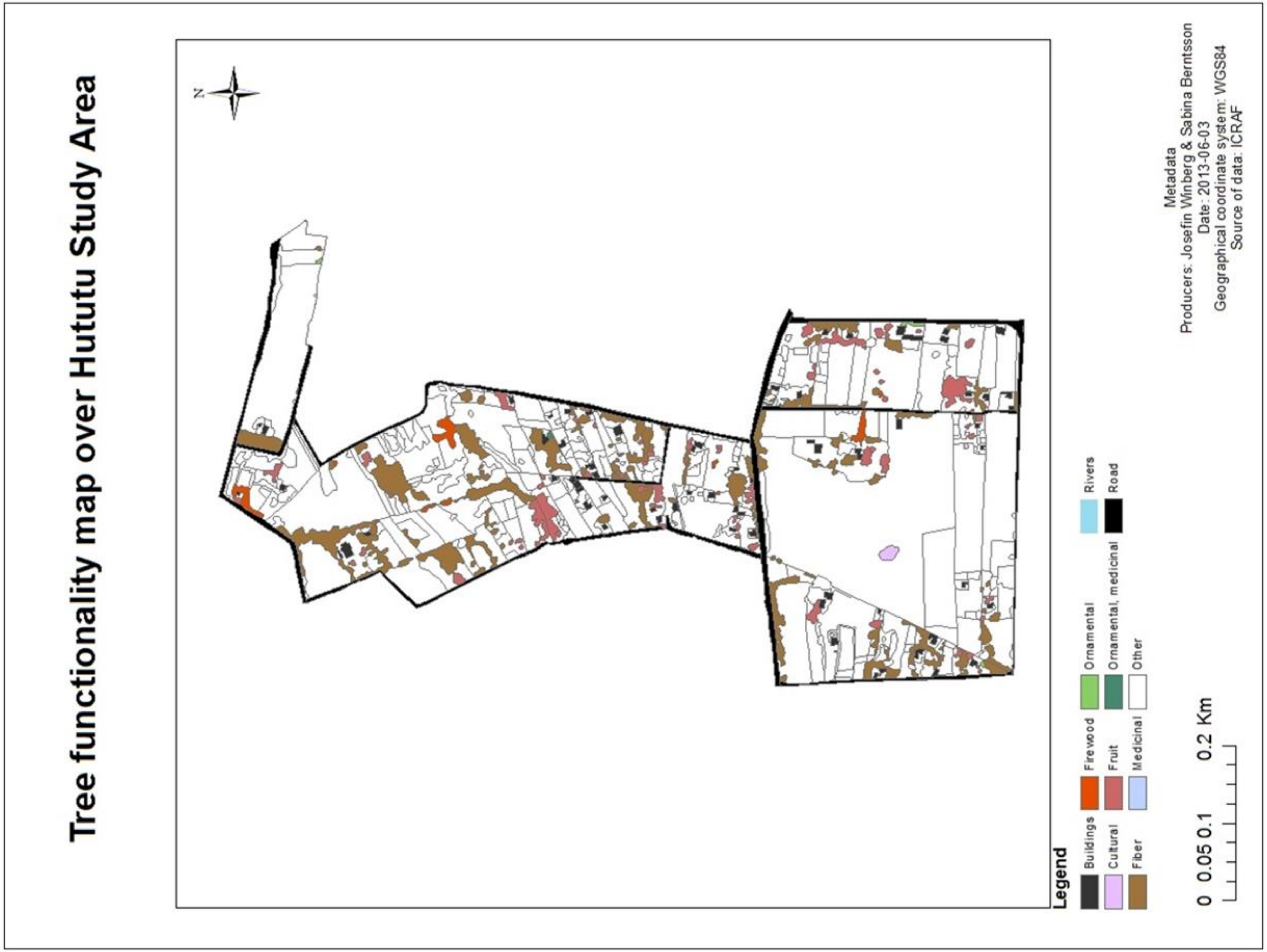

Figure 19: Tree functionality map over Hututu study area, Southern part. The trees are divided into classes based on their main functionality for farmers.

7.3 Water proximity in Hututu

The interviews held with Wamalwa and Musikoyo (2013) revealed information regarding the water use and water proximity in Hututu and how it influences the land cover pattern. They told that Hututu settlement borders to River Nzoia and inside the settlement flows a smaller tributary stream (Musikoyo 2013). The water flow in the smaller stream is not sufficient enough to use for large scale irrigation and since no water transporting infrastructure (water pipes) exist in the area any longer, irrigation from this stream and the River Nzoia only occur to a small extent (Musikoyo 2013; Wamalwa 2013). Bucket irrigation is the irrigation method used and because of that it is only the farmers that have land close to the streams that can irrigate their crop (Musikoyo 2013). When irrigation is possible the farming is not as rain dependent and due to that it is possible to plant earlier in the season and sometimes even off-season (Wamalwa 2013). Crops that can be planted off-season is valuable since the harvest becomes earlier which makes it possible to sell the yields when the market demand is largest which gives higher earns (Musikoyo 2013). It can also be possible to have more harvest times per season. However, it can also be risky to have agriculture close to the river since the lowland areas are swampy and often affected by flooding (Wamalwa 2013).

7.4 Relationship with water proximity

The most interesting findings of the relationship analysis between water proximity and land cover classes as well as the relationship to certain tree functionalities and tree species are presented in the tables below. Table 4, 5 and 6 show the relationship between water proximity and land cover, tree functionality, and tree species.

We consider tree species to be influenced by the closeness to water, either due to water demands or flood resistance, if they mainly are found within 100 meter from the river, and occur with more than 50 percent within 200 meters from the river. The crops can be irrigated by bucket irrigation and it is therefore assumed that there is a relationship with water if they primarily (more than 50%) occur within 100 meters or up to 200 meters from the river. A number of crops and tree species are less frequent in the study area and does only cover a small surface (less than 500 m^2) or are less interesting for our study (for example hedge or buildings for land cover classes, and different combinations of one main tree and other tree species that show the same distribution as the included main tree). These crops and trees are not included in the results with the exception of White Sapote in Table 6.

7.4.1 Land cover and water proximity

The land cover classes that can be considered to have a high water dependency or to be flood resistant as they mainly occur close to the river (within 200 m) are Beans (70.4%), Irish potatoes (100%), Kale (100%), Maize and Vegetables (100%), Maize, Beans and Peas (100%), Millet (100%), Napier grass (69.1%), Shrubs (63.5%), Shrubland (100%), and Sugarcane (99.5%) (Table 4, Fig.19). The land cover classes that can be considered as less water dependent and sensitive to flooding as they mainly occur further away from the river are Grassland (71.6%), Maize and Beans (63.1%), and Sweet potatoes (92.4%) (Table 4, Fig. 20). Banana (55.3%), Maize (51.3%), Trees (57.5%), and Woodland (54.4%) are land cover classes that are quite homogenously distributed and according to the relationship test occur both close to the river and further away.

Table 4: The relationship between selected land cover classes and water proximity. The water proximity is quantified as distance to water courses in meters, and is divided into three classes; 0-100 m, 100-200 m, and >200 m. The area of land cover classes is shown as square meters and as percentage of the area within buffer zone compared to total area of the land cover class.

	Within 100 m		100 - 200 m		>200 m		
Land cover	Area (m2)	% of total area	Area (m2)	% of total area	Area (m2)	% of total area	Total area (m2)
Banana	0	0.0%	1479	44.7%	1826	55.3%	3304
Beans	1020	57.5%	230	13.0%	524	29.6%	1774
Grassland	9722	22.5%	2540	5.9%	30868	71.6%	43130
Homestead	2378	7.7%	9014	29.2%	19446	63.1%	30838
Irish potatoes	456	48.7%	480	51.3%	0	0.0%	937
Kale	4535	100.0%	0	0.0%	0	0.0%	4535
Maize	38601	30.8%	22359	17.8%	64305	51.3%	125265
Maize and Beans	38486	14.3%	60858	22.6%	169824	63.1%	269168
Maize and Vegetables	0	0.0%	612	100.0%	0	0.0%	612
Maize, Beans and Peas	1943	99.0%	20	1.0%	0	0.0%	1962
Millet	457	86.7%	70	13.3%	0	0.0%	527
Napier grass	4791	54.7%	1264	14.4%	2704	30.9%	8759
Shrubland	5527	100.0%	0	0.0%	0	0.0%	5527
Shrubs	3474	54.6%	567	8.9%	2315	36.4%	6356
Sugarcane	25921	93.4%	1707	6.1%	128	0.5%	27755
Sweet potatoes	218	3.7%	226	3.9%	5414	92.4%	5858
Trees	3265	26.6%	1948	15.9%	7052	57.5%	12265
Woodland	15877	29.1%	9008	16.5%	29664	54.4%	54549

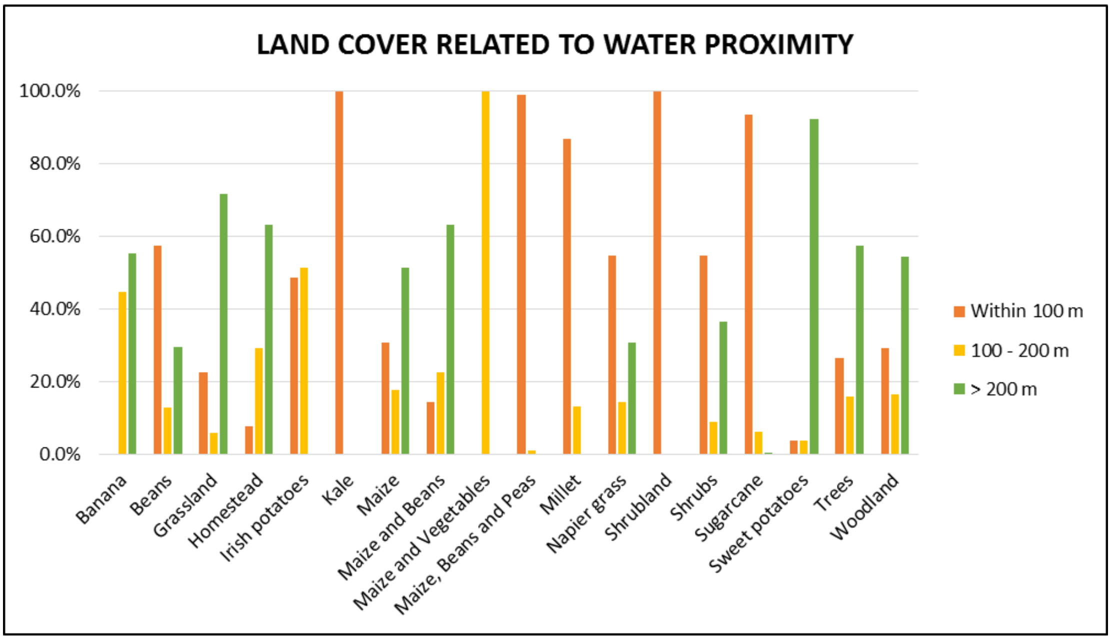

Figure 20: The distribution of selected land cover classes within the distances 0-100 m, 100-200 m, and > 200 m from the river.

7.4.2 Tree functionality and water proximity

The tree functionalities that mainly occur close to the river are Cultural, Firewood and ‘Ornamental, medicinal‘. The tree functionalities that mainly are located further away from the river are Fiber, Fruit, Medicinal and Ornamental (Table 5).

Table 5: The relationship between tree functionalities and water proximity. The water proximity is measured as distance to water courses in meters, and is divided into three classes; 0-100 m, 100-200 m, and >200 m. The area of tree functionality is shown as square meters and as percentage of the area within buffer zone compared to total area of the tree functionality.

	Within 100 m		100 - 200 m		>200 m		
Tree functionality	**Area (m2)**	**% of total area**	**Area (m2)**	**% of total area**	**Area (m2)**	**% of total area**	**Total area (m2)**
Cultural	1158	60.1%	113	5.8%	656	34.1%	1927
Fiber	12645	25.6%	9259	18.7%	27563	55.7%	49467
Firewood	1421	36.6%	560	14.4%	1903	49.0%	3883
Fruit	3233	25.9%	1426	11.4%	7808	62.6%	12467
Medicinal	0	0.0%	0	0.0%	19	100.0%	19
Ornamental	466	44.7%	0	0.0%	575	55.3%	1041
Ornamental, medicinal	219	100.0%	0	0.0%	0	0.0%	219

7.4.3 Tree species and water proximity

The most common tree species and tree species combinations occurring in the study area has been included in the relationship analysis, but the frequency of a tree species has not been considered when analyzing the relationship to water proximity. The species classes that grow close to the water course are Acacia, 'Croton, Cypress, Eucalyptus', 'Croton, Cypress, Grevillea', 'Cypress, Eucalyptus', Eucalyptus, 'Eucalyptus, Grevillea', Sesbania and Syzygium (Table 6). The tree species that grow further away from the water are Avocado, Croton, Cypress, 'Cypress, Eucalyptus, Grevillea', 'Cypress, Grevillea', Grevillea, Guava, Markhamia, and White Sapote (Table 6).

Table 6: The relationship between tree species and water proximity. The water proximity is measured as distance to water courses in meters, and is divided into three classes; 0-100 m, 100-200 m, and >200 m. The area of tree species is shown as square meters and percentage of the area within buffer zone compared to total area of the species.

	Within 100 m		100 - 200 m		>200 m		
Tree species	**Area (m2)**	**% of total area**	**Area (m2)**	**% of total area**	**Area (m2)**	**% of total area**	**Total area (m2)**
Acacia	2349	97.8%	0	0.0%	53	2.2%	2402
Avocado	553	11.7%	872	18.5%	3288	69.8%	4713
Croton	303	35.0%	6	0.7%	556	64.2%	865
Croton, Cypress, Eucalyptus	1079	73.8%	243	16.7%	139	9.5%	1461
Croton, Cypress, Grevillea	386	32.0%	823	68.0%	0	0.0%	1209
Cypress	124	4.8%	449	17.6%	1984	77.6%	2558
Cypress, Eucalyptus	1475	26.4%	1604	28.7%	2514	45.0%	5592
Cypress, Eucalyptus, Grevillea	0	0.0%	436	18.6%	1909	81.4%	2345
Cypress, Grevillea	0	0.0%	1445	32.7%	2976	67.3%	4421
Eucalyptus	6374	39.1%	2076	12.7%	7847	48.1%	16296
Eucalyptus, Grevillea	0	0.0%	570	97.0%	18	3.0%	587
Grevillea	2306	30.6%	764	10.1%	4461	59.2%	7531
Guava	0	0.0%	140	12.5%	984	87.5%	1124
Markhamia	19	0.5%	487	12.8%	3314	86.8%	3820
Sesbania	1370	36.8%	505	13.6%	1848	49.6%	3723
Syzygium	2081	84.1%	169	6.8%	223	9.0%	2474
White sapote	47	14.0%	72	21.5%	217	64.6%	337

7.5 Relationship to proximity to buildings

The land cover class Homestead is included in the analysis of relationship between water proximity and crops (Table 4) as it can be an alternative explanation to the occurrence of land cover classes further away from the river. For example, the classes Trees, Woodland and

Banana are presumptively more correlated to the locations of homesteads than water proximity. To be able to distinguish these relationships from each other was the relationship between proximity to buildings and selected land cover classes and tree functionality also investigated. Table 7 and 8 show the main results from the relationship tests of proximity to buildings and land cover and tree functionality.

Table 7: The relationship between selected land cover classes and proximity to buildings. The proximity to buildings is measured in meters and divided into two classes; within 25 m from a building and > 25 meter from a building. The area of land cover classes is shown as square meters and as percentage of the area within buffer zone compared to total area of the land cover class.

	Within 25 m		>25 m		
Land cover	**Area (m2)**	**% of total area**	**Area (m2)**	**% of total area**	**Total area (m2)**
Banana	1785	54.0%	1519	46.0%	3304
Trees	5092	41.5%	7173	58.5%	12265
Woodland	21165	38.8%	33384	61.2%	54549

The test shows that the occurrence of the selected woody land cover classes is correlated with proximity to buildings. 38.8 %, 41.5 % respectively 54.0 % of the land cover classes occur within 25 meters from a building (Table 7). Numbers over 33% indicate a positive relationship because the buffer zones cover less than 1/3 of the study area (195 300 m^2 compared to 602 100 m^2).

Table 8: The relationship between tree functionality classes and proximity to buildings. The proximity to buildings is measured in meters and divided into two classes; within 25 m from a building and > 25 meter from a building. The area of tree functionality classes is shown as square meters and as percentage of the area within buffer zone compared to total area of the tree functionality class.

	Within 25 m		>25 m		
Tree functionality	**Area (m2)**	**% of total area**	**Area (m2)**	**% of total area**	**Total area (m2)**
Cultural	215	11.1%	1712	88.9%	1927
Fiber	19305	39.0%	30163	61.0%	49467
Firewood	1301	33.5%	2582	66.5%	3883
Fruit	6474	51.9%	5993	48.1%	12467
Medicinal	19	100.0%	0	0.0%	19
Ornamental	185	17.8%	856	82.2%	1041
Ornamental, medicinal	56	25.5%	163	74.5%	219

The closeness to buildings does also have an effect on the distribution of tree functionality. A positive relationship (>33%) can be seen for the classes Fiber, Firewood, Fruit, and Medicinal (Table 8). However, the classes Medicinal and Firewood can be considered to have a weak relationship due to the small area of Medicinal (18.6 m^2) and the low positive relationship for Firewood (33.5 % compared to the threshold value 33 %). A negative relationship occurs for the classes Cultural, Ornamental, and 'Ornamental, medicinal', since more than 33% of the total area occurs more than 25 m from the buildings (Cultural 88.9%, Fiber 61%, Firewood 66.5%, Ornamental 82.2% and 'Ornamental medicinal' 74.5%) (Table 8).

8. Discussion

8.1 Water proximity

In this thesis we decided to investigate if and how decision making at small-scale farms considering crops and trees planted is influenced by water proximity. We defined water proximity as distance to a water course (Appendix I) and have analyzed the results as some crops and trees are preferably planted close to a river since they might be more water dependent than others or alternatively more resistant to flooding. However, proximity to a water body is not the only factor that controls the water availability for plants in the soil. Soil moisture is also influenced by topography, soil type, vegetation and climate (Hess 2010). Still, a change in how the land is used can be seen with distance from the river. This can have a connection to water proximity, but it is also likely to have a strong connection to the population density patterns in Hututu settlement. It is more likely to find crops and trees in agroforestry systems which needs regularly management where people live and have their homesteads, compared to the land close to the river where crops and trees that needs less management can be found.

8.2 How water proximity influences land cover

Figure 20 show the proportion of certain land cover classes within 0-100 m, 100-200 m, and >200 m from the river. Some of the land cover classes only exist within 200 meter from the water courses (Irish potatoes, Kale, 'Maize and Vegetables', 'Maize, Beans and Peas', Millet, Shrubland and Sugarcane) and are hence explained to be influenced by the proximity to water (Fig. 20). However, when analyzing the result it is important to consider the total area of each land cover class. The total cover of several classes is low (Table 6), and it is therefore a risk to reach any conclusion just based on this result. For example is the water need for Irish potato and Millet relatively low, 500-800mm yr^{-1} and 500-1100mm yr^{-1} (Table 1), and there might be other reasons to why these crops only exist within 200m from the watercourses. It is the same for Beans that have 70.4% of the total area close to the watercourses (Fig. 20) and a water requirement of 500-2000mm annually which is relatively low (Table 1). The total cover of Beans is only 1774.23m^2 and the proportion within the buffer zone of 200 m is therefore small (Table 6).

Banana is the most water dependent crop in the area, (Table 1). It covers a small area though (Table 6), and this creates the same analyzing problems as for the previous mentioned crops. About half the proportion of banana occurs within 100-200m from the water courses and half grow more than 200m away (Table 6). Since the area closer to the water course is smaller than the other, banana is more frequent here. However, the high water requirement indicates that there should have been a clearer relationship. Collection of water in dug holes decrease the dependency on continuous water supply, which probably makes other factors more important instead. The influence of proximity to buildings is discussed later in part 8.4.3.

Only 0.5 percent of the Sugarcane occurs further away from the river than 200 meters and 93.4 percent grows within 100 meters from a watercourse (Fig. 20). The reason to why Sugarcane mainly is cultivated close to the river is likely that the water proximity is higher here due to that irrigation is possible. Sugarcane has the third highest water demands of the crops in the area, 1500-2000 mm per year (Table 1). The mean rainfall in Trans Nzoia is around 1300 mm yr^{-1}

and irrigation is therefore necessary to be able to cultivate it. Another influencing factor could be that Sugarcane do not require much management, and could therefore be planted by the river, far away from the homesteads.

Kale is a crop that only occurs within 100 meters around the watercourses (Table 6, Fig. 20). This is surprising since the water requirement for Kale is between 450-1000 mm yr^{-1} which makes it the lowest among all crops that were found in the area (Table 1). The maximum optimal need of 1000 mm yr^{-1} indicates that the yearly rainfall of 1300 mm yr^{-1}in the area would be enough (Table 1). The reason could instead be that Kale is especially tolerant to flooding. That the leaves grow on a stem can contribute to that the crop can withstand waterlogging better than other crops but no such information are found in literature. However, the total area of Kale is not very big (4534.80m^2) and the statistics is maybe just a reflection of the consumption on one specific farm (Table 6). From the detailed land cover maps (Fig. 16 and 17) it can also be seen that it there is few polygons of Kale in the study area.

Napier grass is the crop that requires second most water after banana, nevertheless is the relationship between Napier grass and proximity to water not as strong (69.1%) than for the two previous mentioned crops, Sugarcane and Kale (Fig. 20). Through field observations it was seen that Napier grass often was used as hedges in-between fields which is a way to reduce soil erosion. This can also be seen through visual interpretation of the detailed land cover maps (Fig. 16 and 17). The topography around the water courses is hillier than in the rest of the area and this makes erosion protection extra important here.

There are both mono-cropped maize and maize that are planted together with another crop, mostly beans, in the area. These crop types is the most frequent occurring land cover classes and Maize and beans is by far the most common class, 269,168m^2 compared with 125,265 m^2 for maize and 54,549 m^2 for the third most common class, woodland. The test for relationship show that Maize occurs in the whole area and is relatively homogenously distributed, both when it is planted alone and intercropped with beans (Table 6). However, field observations show that maize that is planted without any beans occur more frequent in the riparian areas than in the rest of the settlement. The statistic in Table 6 can also be analyzed in a different way since mono-cropped Maize is the second most common crop within 100 and 100-200 meter from the river after ‘Maize and beans’ that is most common in the area in general and only have 36.9 percent within 200 meters from the watercourses. 48.7 percent of the land cover class Maize occur within 200 meters from the river (Fig. 20), which gives a higher density of mono-cropped Maize here than in the rest of the settlement. One reason to why Maize is more frequent in the riparian areas could be that beans often are affected by diseases when the conditions become too wet and maize is hence more flood resistant.

Maize has a longer growing season than beans, 1680 GDD compared to780 and according to a study made by O´Callaghan et al. (1994), this leads to that maize are more influenced by drought since beans in contrast to maize are harvested during the rainy season. Observations in field showed that the maize usually was planted earlier along the watercourses thanks to irrigation possibilities (Fig. 21 compared to Fig. 21). It had come further in the growing period and since maize need more GDD than beans (about 900 more) it is possible that the beans already had been harvested.

Figure 21: Large maize growing close to River Nzoia, corncobs have already started to form.
Photo taken 2013-05-07. *Photo: Sabina Berntsson*

Figure 22: Intercropped maize and beans in a field in the middle of Hututu.
Photo taken 2013-05-07. *Photo: Sabina Berntsson*

During the field work it was observed that mono-cultures of maize that were not located close to the water often occur on larger fields. The reason for this could be that machinery is used for farming practices. These large fields with mono-cropping of maize influence the relationship between Maize and closeness to water a lot. There is a good example of this in Fig. 17 since there is a large field of Maize in the southern part that falls outside the buffer zones around the water courses.

The agriculture around the watercourses is more mixed with woody land cover types than the rest of the area (Fig. 23) (Fig. 16 and 17). All Shrublands occur within 100 meters from the water bodies and a large part of the Woodlands also exists here, 29.1% within a distance of 100 meters (Fig. 20). Individually standing shrubs are mainly found within 200 meters from the river but occurs all over the study area (Fig. 20).

Figure 23: Current vegetation around section of River Nzoia, Hututu settlement, 2013. *Photo: Josefin Winberg*

8.2.1 Seasonal influence

During the discussion about crops it is important to remember that the ground truthing and the creation of the detailed land cover map were performed during the long rain season and this probably influence the result. The satellite images were taken in August and October respectively April and December, which is during the short dry period and before and the start of the long rain season. It is possible that other crops are planted during the short rains when the water proximity is lower. For example it has been mentioned that Irish potatoes often are planted together with beans in shorter rain periods. A study like this can obtain more reliable result if it had the possibility to be performed over a longer time and cover all seasons, for example over a whole year.

8.2.2 Size and shape of buffer zones

The buffer zones created for the water proximity analysis are of different shape and total area. The main difference in area occur between the two buffer zones closest to the stream (0-100 m and 100-200 m) and the one further away (>200 m). The buffer zone furthest away from the stream is almost twice the area of the two other buffer zones (304 428 m^2 (>200 m) compared to 169 688 m^2 (0-100 m) and 127 742 m^2 (100-200 m)). This can have influenced our interpretations of the importance of water proximity for some land cover, trees and tree functionality classes, but since we have calculated a proportion of each class within the buffer zone compared to the total area of the class and we are only interested in if the class occur mainly within 200 meter from the stream or further away, this issue could be ignored.

8.3 How water proximity influences distribution of trees

In the test for relationship, the relationship with water proximity was investigated for both tree species and tree functionality. Trends could be seen for some of the tree species, but the clearest patterns occurred for tree functionality.

8.3.1 Relationship between tree functionality and water proximity

Figure 24 show the frequency of each tree functionality within 0-100 m, 100-200 m, and >200 m from the river, and Figure 25 show the total area of each tree functionality class. By only looking at Figure 24, it seems like Cultural and Ornamental, medicinal mainly occur close to the river, whilst the rest of the classes mainly occur more than 200 meters away from the river. But Figure 25 also needs to be considered since some of the tree functionality classes are less frequent than others. For example, the distribution of Medicinal trees in the study area is interesting since the whole class occur more than 200 meters from the river. However, if we look in Figure 25 we see that the class Medicinal only cover 18.62 m^2 which only is a couple of trees. This should be considered while interpreting the results, even though the sample could be representative.

What is more interesting however, is the distribution of the larger classes (Cultural, Fiber, Firewood, Fruit, and Ornamental) (Fig. 25). All of them mainly occur either within 100 meters from the river or more than 200 meters from the river (Fig. 24). None of the classes have a large representation within 100-200 meters from the river (Fig. 24), which tells us that trees in Hututu settlement mainly occur around rivers and where people live.

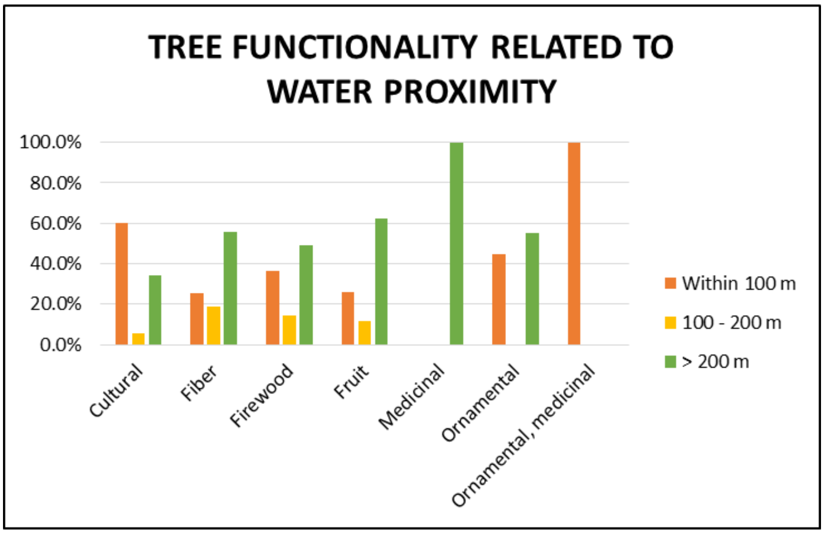

Figure 24. The distribution of tree functionality classes within 0-100 m, 100-200 m, and >200 m from the river.

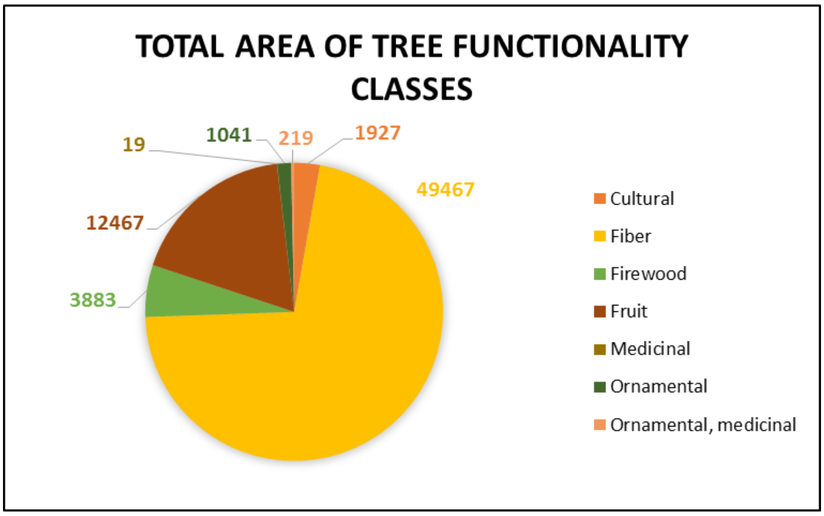

Figure 25. The total area in square meters of the different tree functionality classes.

Firewood and fodder trees are not representatively mapped in the land cover maps since these tree functionalities often are secondary. Trees planted on a farmers homestead need to be carefully selected, pure fodder or firewood trees are normally not prioritized. Even if many farmers have problems with finding fuel for their cooking, firewood trees are not commonly planted. According to Nair (1993) are the reasons that small-scale farmers generally want to have trees that give multiple outputs and that they do not see firewood shortages as existing or impending problem. When there is a deficit of firewood it is replaced by other materials such as crop residuals, maize stoves, and smaller branches. The same material is used for fodder together with the perennial crop Napier grass. When crop residues are removed from the field to be used as fodder or firewood, the amount of organic residues decreases. This leaves less material available for soil quality improvement, and increase the dependency of expensive inorganic fertilizers (Kirungu et al. 2002).

8.3.2 Relationship between tree planting and water proximity

When looking at tree planting in relation to water proximity no real trends can be seen (Fig. 26). The tree species classes that were found to grow closer to a water course are Acacia, 'Croton, Cypress, Eucalyptus', and Syzygium, but if a relationship really occurs is hard to say. However, both Acacia and Syzygium are often found close to a river. Acacia is an old remnant species which may be a leaving from the former riparian areas around the river, and Syzygium is an indigenous fruit tree that mainly grows in wetlands and swampy areas (Appendix II).

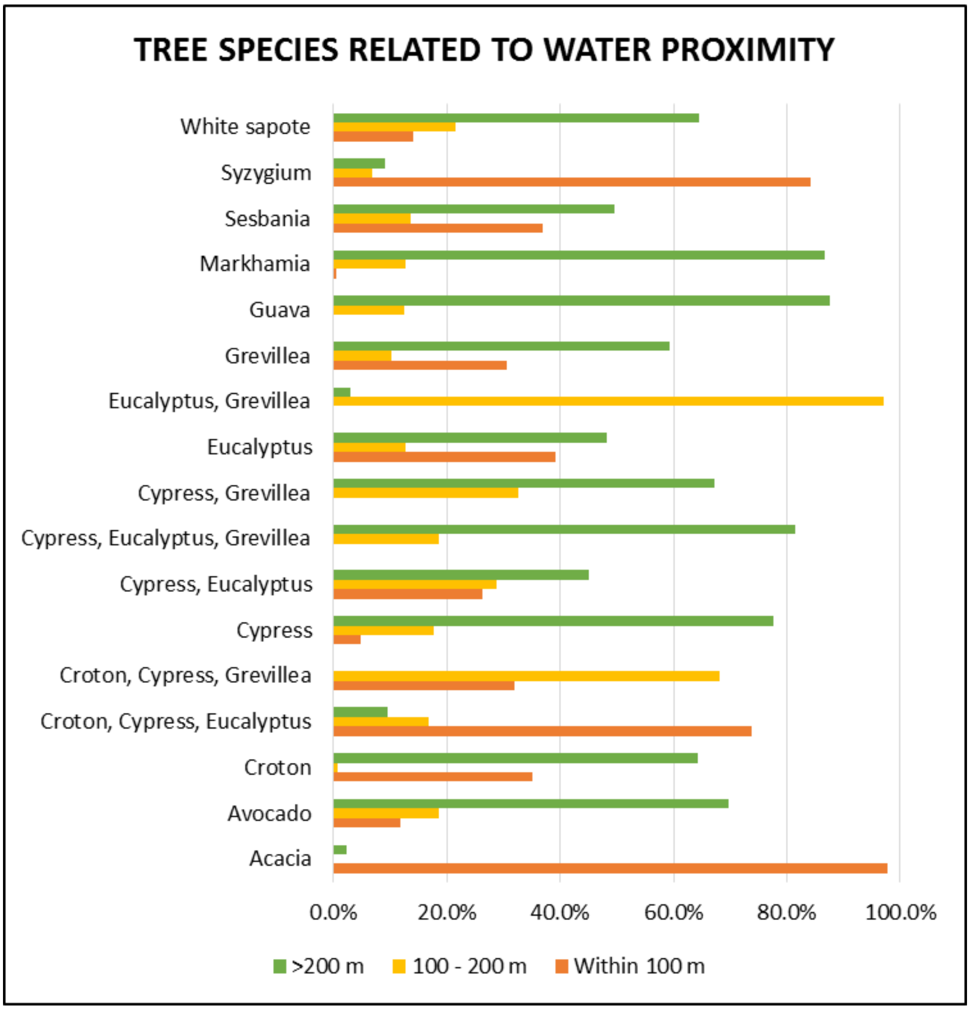

Figure 26. The distribution of the most common tree species and tree species combinations within 0-100 m, 100-200 m, and >200 m from the river.

For the remaining tree species, trends can mainly be seen for the species growing further away from the river. All investigated fruit tree species included in Figure 26 (Avocado, Guava, and White Sapote) mainly grow more than 200 meters from the river (over 60% for all classes). The fiber tree species do also mainly grow further away from the river, but in the mixed classes were Grevillea occurs, a large proportion of the class is located within 100-200 meters from the river. This may be a coincidence since the pure Grevillea class only has a small proportion growing here.

In this analysis has only the tree species and distance to a stream been included. No consideration has been taken to size of the tree and the water need of that specific tree. For future studies these factors would also be interesting to investigate to find further relationships.

8.3.3 Tree planting in Hututu settlement

Table 9: The most common tree species in Hututu study area, based on total area.

Tree species	Total area (m2)
Eucalyptus	16296
Grevillea	7531
Cypress, Eucalyptus	5592
Avocado	4713
Cypress, Grevillea	4421
Markhamia	3820
Sesbania	3723
Cypress	2558
Syzygium	2474
Acacia	2402

In Hututu settlement the most common tree is by far Eucalyptus, followed by Grevillea and 'Cypress, Eucalyptus' (Table 9). These trees are all fiber trees, mainly grown in woodlots or along boundaries. According to the relationship analysis it can be seen that they all mainly grow further away from the river (Table 4, Fig. 26). The wood is either used for construction in the home or sold as timber for industries or poles and posts (Holding et al. 2001). Timber trees planted on the farm is seen as an additional cash income, and the view on timber trees is gradually changing towards a paying farm enterprise (Holding et al. 2001). Kenya's demand for power distribution poles is today larger than the national production, and to solve this problem both Kenya's government and Kenya Forestry Research Institute (KEFRI) has made efforts to create a sustainable supply of Eucalyptus trees in the country (Africa Harvest 2009). However, Eucalyptus requires large amounts of water and planting of Eucalyptus close to rivers has therefore been discouraged (Ong et al. 2006). It is introduced in the area and actively planted by the farmers but not promoted as an agroforestry tree due to its high water demands (Appendix II).

Instead, Grevillea is promoted as a sustainable timber tree in agroforestry, but this tree is also problematic due to its evergreen canopy and high competition with crops for water and nutrients (Ong et al. 2006). To meet the requirements of timber in the study area, a timber tree suitable for agroforestry needs to be introduced. It should have the properties to be fast growing, cheap, and have low competition with crops which is a difficult combination.

8.4 Alternative factors

Water proximity is important but still only one of many factors that explain the land cover and how trees are distributed in the landscape. Some other reasons that we have found to have an impact on land cover in this study are listed below.

8.4.1 Traditions

Small-scale agriculture is the main land use in Hututu settlement and whole Trans Nzoia County and most of the land cover consists of some kind of crop (Fig. 16, 17 and Appendix IV). The prime ambition of small-scale farmers is to be self-contained and grow what is consumed on the homestead. Maize is staple food in Kenya and is often eaten with beans. From the improved land cover maps of Hututu it can also be seen that maize intercropped with beans is the most common land cover class in the area and are grown all over the settlement (Fig. 16 and 17).

Maize that is grown together with beans cover 44.7 percentage of the total area (269168 m^2/601 858 m^2).

8.4.2 Historical land cover

The occurrence of trees is more frequent around the homesteads and the land close to the watercourse seems to be more diverse and mix with other land cover classes than the rest of the settlement. From the interviews with Wamalwa and Musikoyo (2013) it is revealed that the ground around River Nzoia previously consisted of a forest and was the last land to be inhibited. The area around the tributary stream was formerly swampy and thus consisted of thick and wild vegetation. The reason for why the land cover in Hututu looks as it does today can be that the old land cover partly is left and hence is the vegetation around the water course less cultivated.

From the analysis of tree functionalities it can be seen that the occurring trees in the riparian areas is on one hand actively designed and on the other trees that are left in the landscape. Cultural, ornamental and medicinal trees around the watercourses are likely residual trees from the time when the area where more rampant.

8.4.3 Proximity to buildings

The land cover classes that seem to have a positive relationship with proximity to buildings are the woody land cover classes; Banana, Trees, and Woodland. They all mainly occur within homesteads which can have several reasons. Homesteads are usually fenced which creates a protection for a newly planted tree, both from grazing by cattle and from stealing. To plant trees and fruits close to your home could also be for shading, protection, and to have firewood, fodder, fiber, and fruits easily available.

The closeness to buildings does also have an effect on the distribution of tree functionality. A positive relationship can be seen for the classes Fiber, Firewood, Fruit, and Medicinal, whereas a negative relationship occurs for the classes Cultural, Ornamental, and ’Ornamental, medicinal’. The distribution of tree functionalities is clearly correlated to where people live. Around the houses is commonly trees planted with a function that can provide a family with products. Further away, often close to the river, we can find the other tree species with cultural and ornamental values (see section 8.2.2).

8.5 Tree density

The tree cover in Hututu settlement is denser than in many other agricultural landscapes, but according to the interviews with Wamalwa and Musikoyo (2013) a large decrease has occurred in the later years. Even though agroforestry have been promoted in the area not all the farmers introduced have it and there are still problems with lack of knowledge of some of the tree functions. The reason for why more trees are not planted is several and it is important to remember that a large population puts heavy pressure on the resources and this has created a general decrease in tree cover. The trees do not give direct reward as food and this makes it less motivating to finance it since it is a long term investment.

Another explanation to why farmers do not plant more trees on their land even though the needs are high could be lack of knowledge. However, by an interview study made by Jerneck and Olsson (2013) it could be concluded that farmers in NW Kenya generally have good knowledge about trees and how it benefit the agriculture. Instead the main reason to why farmers in this study did not implement agroforestry was due to financial and labor shortages. The result showed that farmer's willingness to implement agroforestry foremost is dependent on if they experience food security or not. Investments in agroforestry are often a long-term process (Haldin et al. 2000). It takes several years before harvest and the seedlings are vulnerable against grazing animals and weather types such as heavy rains (Jerneck and Olsson 2013). Small-scale farmers that do not have enough food throughout the whole year do not afford to take risks and invest in unpredictable outcomes as tree planting. When people have problems with their daily needs they also tend to be hindered in their long term thinking and the worry creates a mental barrier (Jerneck and Olsson 2013).

Another problem with tree planting is time. Trees do not require a lot of labor relative to crops, e.g. planting and harvesting. However, tree planting is seen as an activity that competes with other activities and is time consuming in the early stages with planting, weeding, watering and protection (Jerneck and Olsson 2013). Farmers that do not experience food security often have less extra time since they need to buy parts of their food and hence are more dependent on money and need to spend time in income generating activities such as basket making or off-farm work (Jerneck and Olsson 2013).

The situation with few trees is specially a problem when it comes to the supply of firewood and it has been showed to partly be due to gender issues. It is usually the women that collect firewood but the man is the head of the family and decides what should be planted on the land (Biggelaar 1996.). Further there is sometimes a traditional ban for women to plant trees since tree planting used to establish ownership over the land in many African countries (Biggelaar 1996.). Tree planting are traditional the man's work but some shifts in this roles are occurring so that the husband and wife help each other and take decisions together (Biggelaar 1996). According to the interview with Makokha (2013), the most successful agroforestry is achieved when there is an understanding between the man and the woman in the family.

8.6 Map accuracy

The accuracy evaluation of the land cover maps show that different settlements have different quality and that the classification accuracy generally is low (considering it is a high-resolution map with many small details mapped). The overall accuracy is around 50 percent for all settlements with 58.1 percent for the most accurate map, Hututu and 47.3 percent for Yuya that has lowest accuracy (Table 3). Since interpretation of satellite images is difficult on this very detailed level of objects, the suggested improvement should be done by field observations and field data collections. A decrease in the number of land cover classes by aggregating similar classes could also improve the map accuracy, but would then result in a less detailed map.

8.6.1 Possible sources of error

The low accuracy of the land cover maps can be due to different reasons. Difficulties with the interpretation and the resolution of the satellite images are some reasons. Further, external factors, such as lens distortions and clouds, influence the quality of the images and can lead to problems with the raw data. Relatively small objects are included in the classification and they can generally have been difficult to distinguish. The resolution of the satellite images are 0.60

m which is good but maybe are too small objects included in the classification. Moreover, it is possible that the interpretation have been influenced by shadows which change the appearance of objects and possible can have hidden important land features.

Figure 27: The spatial mismatch between two satellite images. Red circles have been drawn where roads are supposed to meet.

The low accuracy could also have resulted from problems with the data. During the evaluation process was an inconsistency error between the satellite images found. Where the images overlapped they did not always coincide with each other (Fig. 27). The land cover maps had been created without any compensation for this fault and the error was therefore transferred. Due to time constrain and lack of proper metadata for the satellite images and land cover map this problem could not be solved during this project.

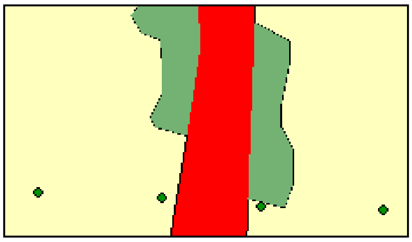

Figure 28: An example on how the position of the ground truth points influence the evaluation. The third point from left is situated in the annual crop field just outside the woodland. It is ground truthed as woodland and mapped as annual crop.

Since small land features are mapped and the landscape is shifting it is important to have the exact right locations attributed to each evaluation point. During the road sampling was ground truth data gathered at two different distances from the road, 1 meter and 10 meter. The coordinates were taken from the car at the road and were later moved manually to the correct locations. Since the distances were estimated and not measured in field it can have led to wrongly positions and this could also be seen when the ground truth points were compared with the land cover maps (Fig. 28).

Despite of this problem the sampling method was chosen based on field observations and studies of the maps which showed that the small-scale farming made the accessibility in the district limited. By using roads the sampling was more time-efficient and a large number of land cover classes could be represented.

The accuracy of the GPS varied between 4 and 11 meters during the sampling and it can be significant in a small-scale setting. There is also a possibility that the GPS have a systematic or random error. This could unfortunately not be controlled due to the spatial mismatch of the satellite images and maps, and the poor access to documents of how the data had been handled before which caused uncertainties about the reference system and projection for the satellite images and the maps.

8.6.2 Problematic land cover classes

Some land cover classes are often wrongly classified without any pattern seen of what it has been mixed up with, e.g. Shrubland, Grassland and Coffee. Others, Hedge and Perennial crops have often been confused to the same land classes. Perennial crops is often mixed up with Annual crops and the reason for this can of course be that they were difficult to interpret, but agricultural landscapes are dynamic and land cover changes a lot over time. Fields that were planted with Perennial crops when the satellite images were taken can have been shifted to Annual crops today and vice versa.

Figure 29: Hedge or woodland? *Photo: Josefin Winberg*

Hedges are narrow features and can have been difficult to detect. It is often classified as Annual crops instead which is the most common land cover class in the area. Sometimes it has also been confused with Woodland. According to the classification key (Appendix III), trees in rows should be included in the hedge class, the similarity between this classes may have caused problems during the interpretation however. Especially since the estimation of the width of the tree is difficult when shadows from the trees occur (Fig. 29).

8.6.3 Differences in accuracy between the settlements

The range of the overall accuracy for the land cover maps is about 10 percentage units between the settlement with highest and lowest accuracy (Hututu and Yuya) and the Kappa value ranges between 0.459 and 0.331 (Table 3). This occurs even though the settlements roughly are similar regarding field size and land cover, have approximately the same number of classes, and the satellite images have the same resolution and are interpreted using the same classification key. Factors that might have influenced are that the temporal land cover changes might be unequally large between the settlements and variations in how the interpretation is performed, i.e. if it is done by different persons, in different detail or with different time limits. Subjectivity in classification is additionally a contributing factor if different people have performed the interpretations. Different persons have different ideas of how the land cover should be classed i.e. the difference between a grassland with shrubs and a shrubland.

Other explanations for the quality dissimilarity can be that the classes that are evaluated are not the same for all districts, nor are the extension of them. If classes that are hard to interpret occur more often in the ground truth data the potential of a negative influence of overall accuracy and Kappa statistic is higher. During the road sampling, that counted for most of the gathered data, the spread between different classes were due to chance. But the selective road sampling was directed by the evaluators. This source of error could have been reduced if a selected number of points were chosen for each occurring land cover class. This type of collection method also has disadvantages however. It would not have been possible to perform road sampling which is faster, and it would not have represented the differences between the areas.

9. Conclusions

The evaluated land cover maps have a low overall accuracy and Kappa values and if they are to be used for a study on detailed scale, like this one, they should be improved.

Our results show that water proximity has an influence on land cover and to some extent on the tree species planted. Crops and trees grown close to the river are mainly more water dependent, water resistant, or benefit from wet conditions. Crops can be planted earlier and grow faster, but they are also more vulnerable to flooding and waterlogging of soils. Water proximity also influences the distribution of tree functionality indirectly. It can be seen that trees that require less management often are planted close to the river.

However, water proximity alone does not explain the design of the landscape. Woody land cover classes (Banana, Trees, and Woodland) have a positive relationship with proximity to buildings. A relationship can also be seen for tree functionality as a positive relationship occurs for fruit trees, fiber trees, and firewood trees. The historical land cover and population patterns probably also have an influence on how the landscape look like today. Yet, a full understanding of distribution of tree functionality, tree species, and land cover is not obtained. Several socio-economic factors like farm size, gender equality, income, and education influence how and where farmers select to grow their trees and crops, and species are often selected without any knowledge about their interactions.

Acknowledgments

By having the opportunity to write our thesis in Kenya we have learned and experienced so much more than what it is presented in this report. We are therefore very grateful to the Swedish International Cooperation Agency (Sida) and the Swedish University of Agriculture Sciences (SLU) for giving us this chance. Without the scholarship this study would not have been possible. Thanks to Vi Agroforestry in Kitale, Kenya, for great hospitality and for help and guidance in our work in Kitale. A special thanks to our supervisor Ylva Nyberg, our patient driver Festus, and our good friend and translator Sarah that filled in the gaps both in language and local knowledge. We would also like to mention Emely and Margaret, and thank Robert Musikoyo, William Makokha and Godfrey Wamalwa for answering our questions and making our field work possible.

We would like to express our gratefulness to Timothy Pagella and Ingrid Öborn at World Agroforestry Centre (ICRAF) for all the help and advice. Your visit in Kitale brought new energy to our project and made us see our project with new eyes. An additional thanks to Ingrid for inviting us to your home in Nairobi, and Tim for all the help when we were back in Sweden.

A great thank you to the Department of Physical Geography and Ecosystem Science. To our supervisor Jonas Ardö for his support and understanding, and to Ulrik Mårtensson for help with the scholarship application. Thanks to SLU and Mattias Jonsson for providing us with the data material.

A last thanks to Theresa, Ibrahim, Elvis and all the other staff at Karibuni Lodge for providing us with a home in Kitale, and to Simon, Julia and Johan for being our Swedish family in Kenya.

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Appendix I – Definitions

Food security

"Food security exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life " (World Food Summit, 1996).

Gross domestic production, GDP

William A. McEachern defines GDP as: "*GDP measures the market value of all final goods and services produced during a year by resources located in [the country], regardless of who owns the resources."* (McEachern, 2010).

In this report is GDP valued in PPP (purchasing power parity) per capita, which means that the index is valued at prices prevailing in the United States for the given year divided by the population as of 1 July the same year (CIA, n.d.).

Growing degree-days, GDD

GDD is a heat index that relates the development of a plant to the environmental air temperature (Schneider, 2011). Growth is dependent on the temperature and plants have different heat requirements, both for reaching maturity and to go from one part of the life cycle to another (Miller, *et al*., 2001). GDD is the accumulated heat over time and are calculated by adding the daily average temperature (the maximum and minimum temperatures divided by two) and subtracting the base temperature of the specific crop (Miller, *et al*., 2001). Every day are assigned a specific heat value and this are added together to tell how far the plant have come in the development stage (Miller, *et al*., 2001). The base temperature is dependent on the life cycle of the plant and usually ranges between 5ºC to 10ºC (Schneider, 2011).Temperatures lower than the base temperature is too cold for the growth of a specific plant and is represented by zero in the equation (Miller, *et al*., 2001).

Land cover

Land cover is the physical cover of the earth´s surface and includes vegetation, anthropogenic features and often also water bodies (Di Gregorio and Jansen, 1998). It can be determined by remote sensing from aerial and satellite imagery (NOAA, n.d.)

Land use

Land use is how humans use the landscape, both for production, maintaining and transformation (NOAA, n.d. : Di Gregorio and Jansen, 1998).The same land cover can be used in various ways e.g. a grassland can be used as pasture or being a football pitch (NOAA, n.d.). Different land cover types can have the same function as well e.g. a beach and a park is both used for recreation (Di Gregorio and Jansen, 1998).

Small-scale fields

Small-scale agriculture do not have a general definition (HLPE, 2013). It varies with time and at regional, national and local levels (HLPE, 2013). Moreover, small-scale farms are often

defined by the relationship to larger commercial holdings on one hand and landless workers on the other and several factors need to be taken in to account (HLPE, 2013).
The farm size limit that Vi Agroforestry uses for their work in Kenya is 2 ha which also the threshold commonly used in literature (Nyberg, 2013: HLPE, 2013). Classifications only based on this factor can be misleading however. Smallholdings are firstly classified due to that they are scarce on resources, especially land to fulfill basic needs and achieve a sustainable agriculture (HLPE, 2013). Small-scale farmers mostly or only rely on the outcomes from the farm, either in kind or in cash and are on the same time producers and consumers (HLPE, 2013). The work labour derives from the family (including one or more households), but off-farm activities are often important to get additional income and to reduce the risk through decreasing the yield dependency (HLPE, 2013).

In this thesis, all this factors are taken into account for defining small scale agriculture.

Water proximity

In this thesis we have defined water proximity as distance to the nearest water course. Not only does the proximity to water influence the crops and trees by flooding, fields closer to a stream can more easily be irrigated. From the interview that was held with Wamalwa 2013 it was revealed that the study area has no water transport structure such as water pipes, and irrigation of crops far away from the water course is therefore not possible. Even though proximity to a water course strongly influence irrigation possibilities, other factors could also be important. We have not considered topography in this thesis, but topography can be a crucial factor considering water availability and if irrigation is likely to occur or not.

Appendix II – Tree species characteristics

After an interview with William Makokha, Vi Agroforestry, Kitale. 14/5 – 2013

Avocado (*Persea americana*)

Avocado is grown for the fruits, but it also produce firewood and has medicinal benefits. Avocado requires good soils and needs to be managed every year to produce fruits. Is not suitable to grow together with crops due to shading. Seedlings are cheap to buy.

Avocado fruits. *Photo: Simon Hallberg*

Bredelia micrantha

Bredelia is an indigenous tree that mainly is used for firewood. The wood produce very little smoke during fire which makes it suitable for cooking indoors. The tree is also used for timber since it is termite resistant. It used to be promoted by Vi Agroforestry but is no longer due to low demand from farmers. Bredelia grows in wet conditions and as long as the water supply is sufficient it has low competition with crops. Seedlings are cheap to buy.

Castor seed oil tree (*Ricinus communis*)

Castor seed oil tree used to be grown for oil production, but due to decreased demand this is no longer the main reason. The timber suits very well for making stakes for banana plants, but the seeds do also have medicinal benefits. Castor seed oil tree has low competition with crops and is resistant to water extremes. Is easy and cheap to regenerate from seeds and wildings. Is not promoted by Vi Agroforestry.

Cordia Africana

Cordia is an indigenous tree that is promoted by Vi Agroforestry. It is mainly used for timber, but also contributes to increased soil fertility and water conservation since it drops a large amount of leaves during the dry season. The coverage of leaves on the soil decreases the evaporation from the soil and protects from erosion. Cordia has low competition with crops if branches are pruned to avoid too much shade. The branches can then be used for firewood. The seedlings are cheap to buy.

Croton Macrostachyus and *Croton Megalocarpus*

Croton Macrostachyus is a deciduous tree mainly used for timber, but also improves the soil fertility and water conditions. It is indigenous and promoted by Vi Agroforestry. The price of the seedlings is medium. Croton Megalocarpus grows faster than Macrostachyus and produce more timber, but have more competition with crops. The price of the seedlings is low.

Cypress (*Cupressus)*

Cypress is a timber tree that is not promoted by Vi Agroforestry. It is very competitive with crops, but still popular to grow due to its fast growth and good timber.

Elgon teak (*Olea capensis*)

Elgon teak is an indigenous timber tree promoted by Vi Agroforestry. The branches are used for firewood and charcoal and the wood do not need to be dried before use. Elgon teak grows in moist conditions and has therefore a positive impact on soil and water conservation. The seedlings are rare and expensive.

Erythrina abyssinica

Erythrina is an indigenous ornamental tree with high cultural value. It is traditionally not used for firewood or timber, but has some medicinal benefits. It has low competition with crops.

Eucalyptus

Eucalyptus is an introduced timber tree that has very high competition with crops. It is popular to grow due to its fast growth and high timber quality, but the tree requires a lot of water and nutrients, and where Eucalyptus has been grown the soil is depleted. Eucalyptus is promoted by the Kenya Forestry Research Institute (KEFRI) and Kenya Powers to create a sustainable supply of timber for power distribution poles. The seedlings are cheap, but the seeds require fire to germinate.

Eucalyptus trees. *Photo: Josefin Winberg*

Ficus Benjamina

Ficus Benjamina is an ornamental tree often used for shading coffee, but the branches can also be used for firewood. It is not suitable for agroforestry due to its high nutrient dependency and surface roots. Regeneration is complicated and seedlings are therefore expensive.

Ficus Sycomorus

Ficus Sycomorus is a deciduous ornamental tree but is also used for shading in coffee plantations and timber. Additionally it improves the soil quality, but competes with crops due to its large roots. The tree produces edible fruits that mainly are given to livestock. The seedlings are expensive because of the complicated regeneration and high demand.

Fraxinus

Fraxinus is an ornamental tree, appreciated for its flowers. It is often used for bee forage, but the wood can also be used for firewood. The competition with crops is low, but the trees are also very uncommon.

Grevillea robusta

Grevillea is a common timber tree, promoted by Vi Agroforestry. The tree produces a lot of branches which makes it suitable for firewood as well. It has low competition with crops, but due to the low access and high demand for seeds, they are very expensive.

Leaves of Grevillea. *Photo: Josefin Winberg*

Guava (*Psidium guajava*)

Guava is a common fruit tree promoted by Vi Agroforestry. Pruned branches are also used for firewood. The competition with crops is moderate. The tree is very easy to regenerate so seedlings are cheap.

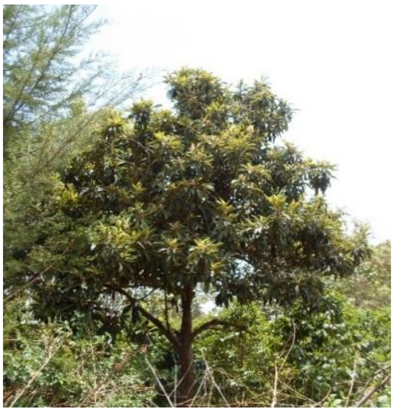
Jak fruit (*Artocarpus heterophyllus*)

Jak fruit trees are uncommon in the area since they require warmer climate. The tree used to be promoted by Vi Agroforestry, but could not be grown successfully. The competition with crops is average and the seedlings are cheap.

Jak fruit tree. *Photo: Sabina Berntsson*

Loquat *(Eriobotrya japonica)*

Loquat is a common fruit tree in Trans Nzoia district, and is often planted for its esthetical value. The branches can also be used for firewood. The competition with crops is average and the seedlings are cheap.



Loquat tree. *Photo: Josefin Winberg*

Mango *(Mangifera indica)*

Mango normally not grown in this area since the climate is too cold for the tree to produce any fruits. The competition with crops is average and seedlings are cheap.

Mango tree. *Photo: Sabina Berntsson*

Markhamia lutea

Markhamia is an indigenous tree mainly used for timber that is promoted by Vi Agroforestry. It is also suitable for firewood. The roots of Markhamia go deep and the tree therefor has low competition with crops. Seedlings from Markhamia are spread by the wind and hard to obtain, and the price of seedlings are therefore high.

Prunus Africana

Prunus is a timber tree that is promoted by Vi Agroforestry. The tree is indigenous and has traditionally a high medicinal value. Competition with crops is low, but the tree is not common since the seedlings are expensive.

Sesbania sesban

Sesbania is indigenous and a commonly planted firewood tree. It is also used as stakes for banana or vegetable. Sesbania is nitrogen fixing and contributes to increased soil fertility. The tree can easily regenerate and the seeds are cheap.

Leaves of Sesbania. *Photo: Sabina Berntsson*

Seedling of Sesbania. *Photo: Simon Hallberg*

Spathodea campanulata

Spathodea is an ornamental tree, also used for shading. It is indigenous and can also be used for timber and firewood. The tree has low competition with crops and seedlings are cheap.

Syzygium

Syzygium is an indigenous fruit tree that grows in wetlands and swampy areas. If the tree is planted at the right place, it has low competition with crops and can contribute to water conservation. Syzygium can also be used for timber and firewood. The tree regenerates itself and the seeds are cheap.

White Sapote *(Casimiroa edulis)*

White Sapote is a common fruit tree that has low competition with crops. The wood is suitable for firewood. The price of seedlings is low.

Appendix III – Land cover classification key

Land cover Classification Scheme used in mapping in the Kitale area

1. **Agriculture**
    i. **Annual crops** (area with maize, wheat, beam-maize mixed other dominant crops known to grown within study), also cultivated areas for such crops
    ii. **Perennial crops** (other than coffee, such tea, orchards, banana, etc.)
    iii. **Coffee** (Area purely under coffee, or coffee mixed with crops)
2. **Vegetation cover**
    i. **Woodland** (A mosaic of several trees grown within or outside farmlands)
    ii. **Shrubland** (A mosaic of several shrubs or thickets grown within and outside farmland)
    iii. **Tree(s)-** A single or less than 3 spatial separated tree system within or outside farmland
    iv. **Shrub (s)-**A single or less 3 spatial separated shrub system within or outside farmland
    v. **Hedge (s)-** A single line of trees or shrubs growth within the boundary of farms or homestead
    vi. **Grassland-** Open grassland areas or pastors within minimal signs of cultivation.
    vii. **Riverine-** Vegetation areas around river systems
3. **Water bodies**
    i. **River-** Line water body systems with water presence during data interpretation
    ii. **Lakes-** None linear water body (water mass) water presence during data interpretation
    iii. **Water-** Lakes like water body that larger than water ponds
    iv. **Water pond-** a regular shape water body located with or outside farmland and relatively smaller than then the lakes.
4. **Man-made features**
    i. **Building**- any structure for human habitation or other use.
    ii. **School Compound**- An open area with a mixture of long buildings and house based structures within large field of grassland with or without few trees but surrounded by hedges.
    iii. **Homestead Compound**-An open area with one or more small buildings within or adjacent to small scale farms or grassland or cultivated areas sometimes surrounding with hedges.
    iv. **Open Market area**- An open area within a complex or canopy of buildings attached or detached to each, and adjacent or within road networks.
    v. **Roads** – Linear road features either tarmac, murrum, foot path to provide accessibility by motor vehicles, bicycles or foot.

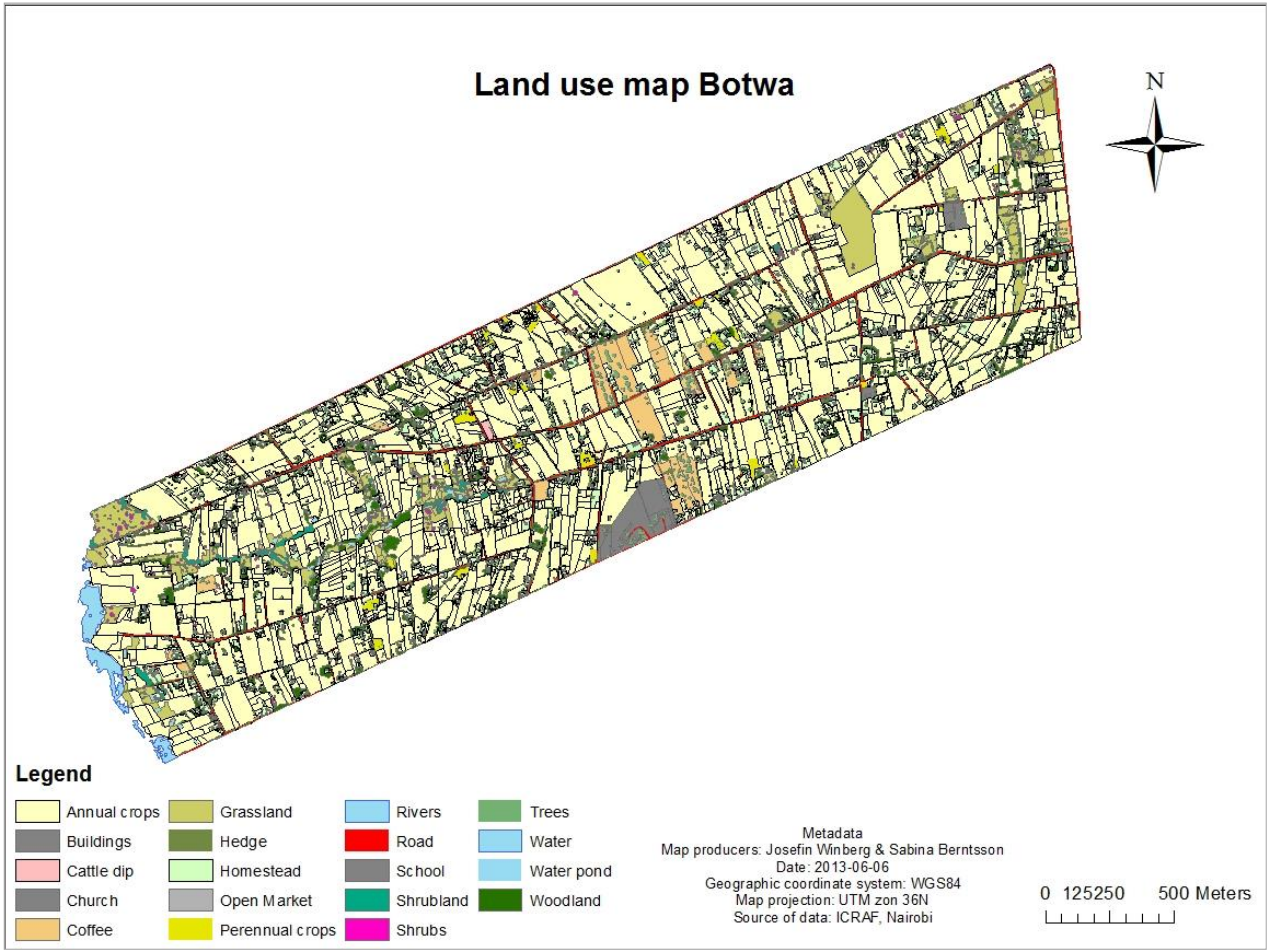
vi. **Cattle dip area**- relatively a small and open enclosed with hedges having a single and thin long structure with pattern of paths from both end.

vii. **Church Compound**- A relatively medium size open space enclosed by hedges with either singe or two building structures, with one having a cross or T-shaped outlook.

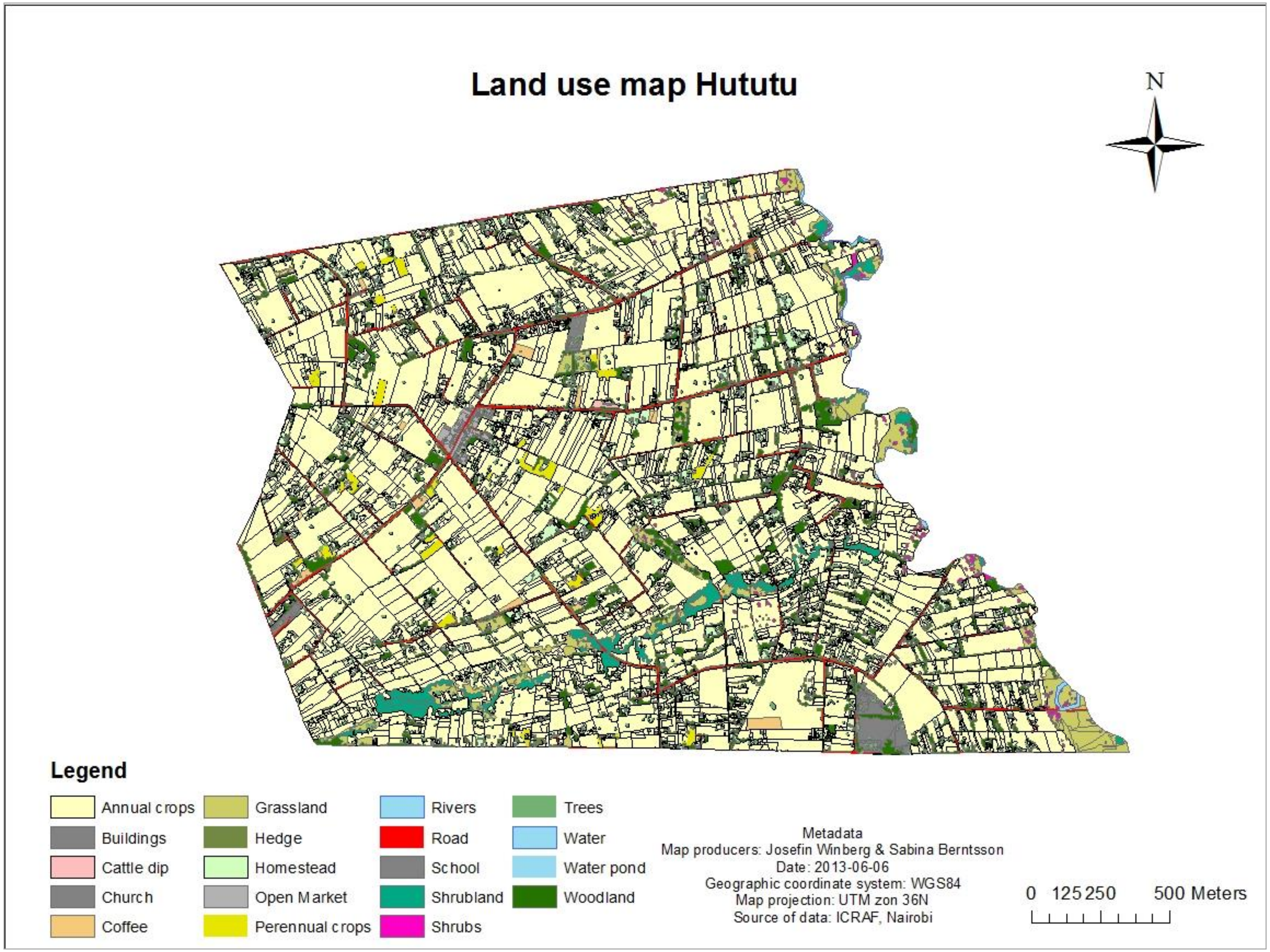
viii. **Industrial sites**- Areas with long structure (building) similar to school compound enclosed by hedges, but lack large fields of grassland, and dominantly located within agricultural lands.

Appendix IV – Evaluated land cover maps

Botwa



Hututu


Land use map Hututu
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Annual crops
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Cattle dip
Church
Coffee
Grassland
Hedge
Homestead
Open Market
Perennual crops
Rivers
Road
School
Shrubland
Shrubs
Trees
Water
Water pond
Woodland
Metadata
Map producers: Josefin Winberg & Sabina Berntsson
Date: 2013-06-06
Geographic coordinate system: WGS84
Map projection: UTM zon 36N
Source of data: ICRAF, Nairobi
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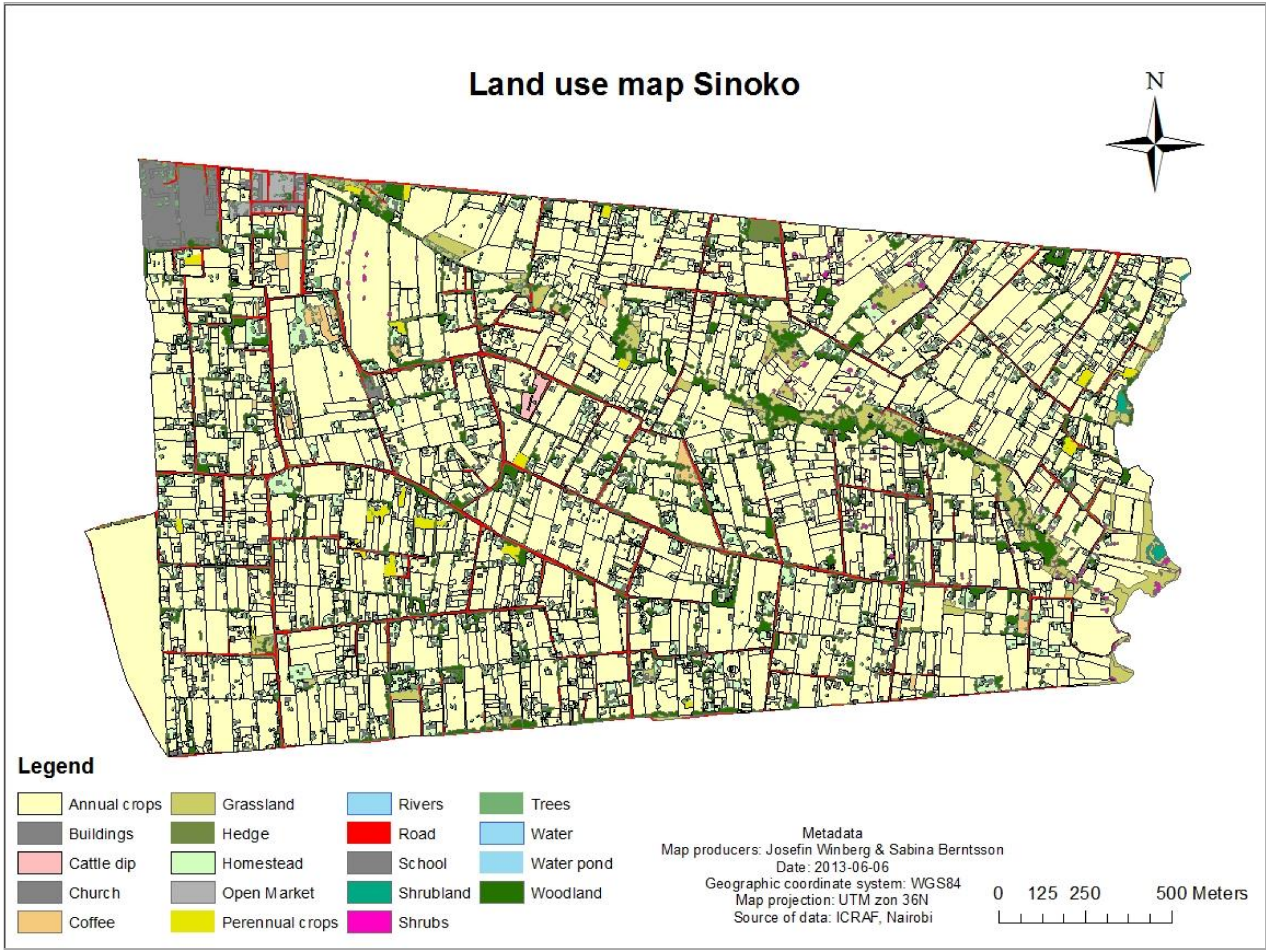
Sinoko


Land use map Sinoko
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Source of data: ICRAF, Nairobi
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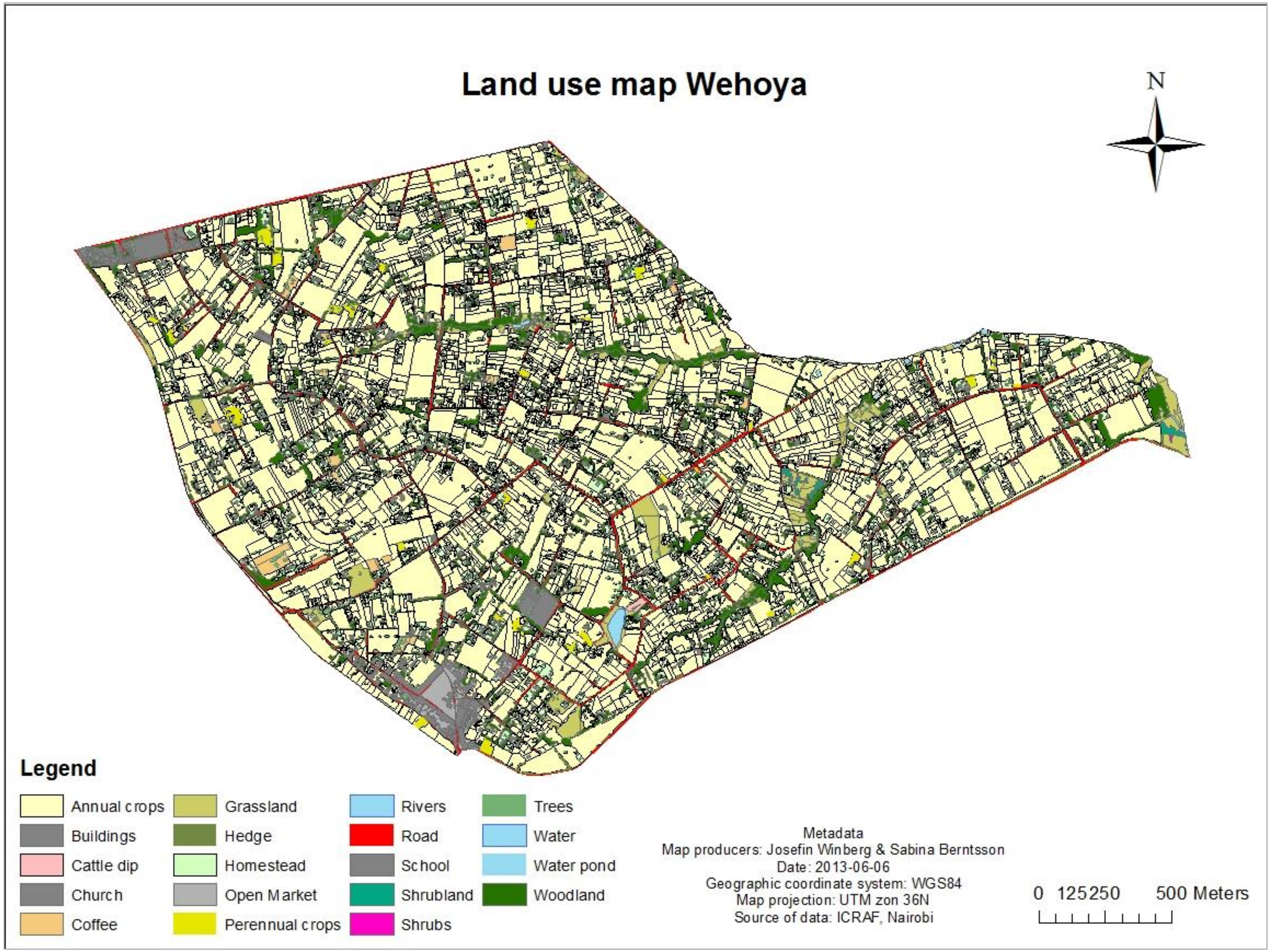

Land use map Wehoya
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Map producers: Josefin Winberg & Sabina Berntsson
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Geographic coordinate system: WGS84
Map projection: UTM zon 36N
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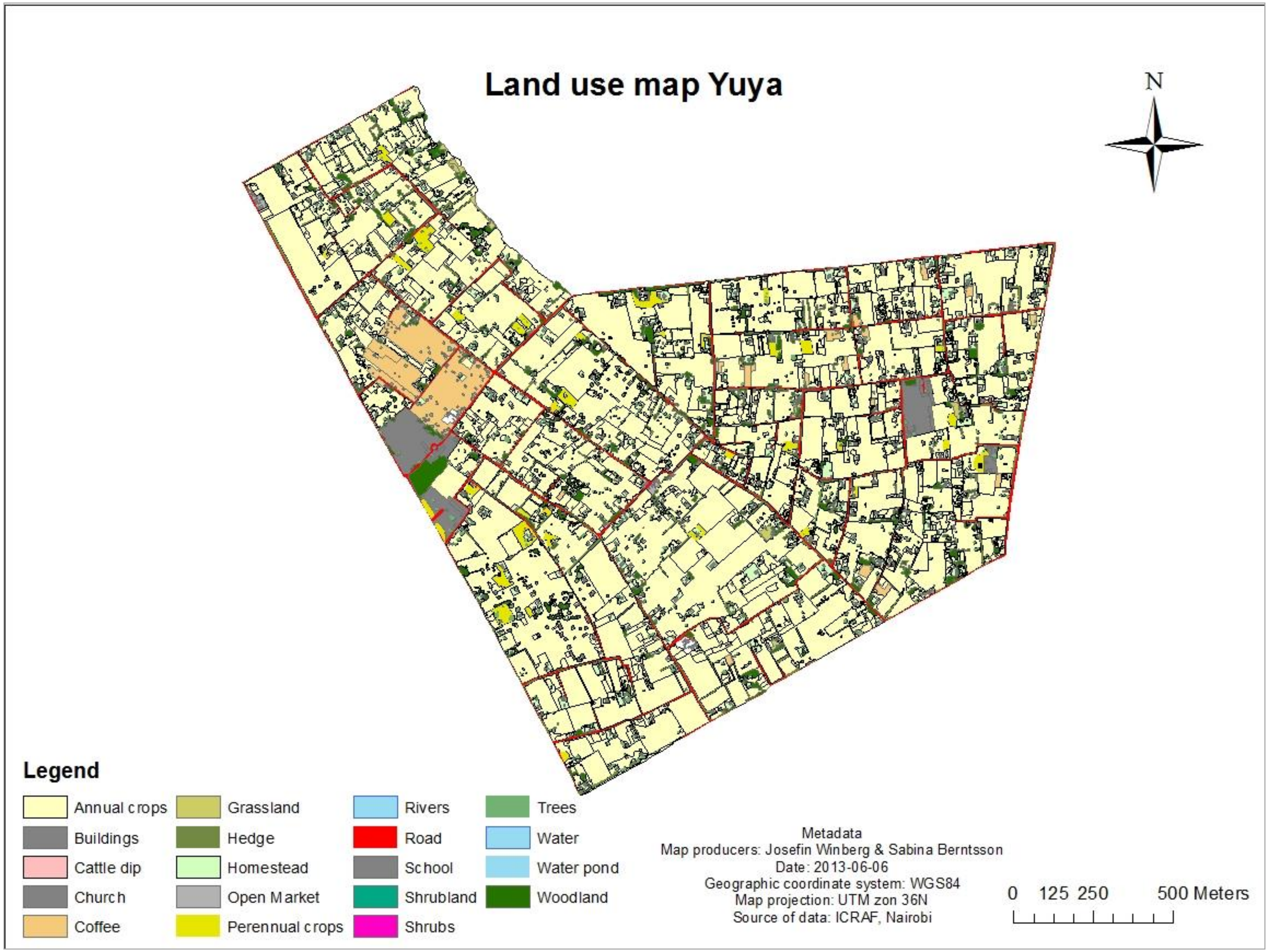
Yuya



Land use map Yuya
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Annual crops
Buildings
Cattle dip
Church
Coffee
Grassland
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Homestead
Open Market
Perennual crops
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Woodland
Metadata
Map producers: Josefin Winberg & Sabina Berntsson
Date: 2013-06-06
Geographic coordinate system: WGS84
Map projection: UTM zon 36N
Source of data: ICRAF, Nairobi
0 125 250 500 Meters

Appendix V – Error matrices

Botwa

	A	P	Cof.	W-l	S-l	T	Shr.	Hed.	G-l	Riv.	Wat.	W.p	Buil.	Sch.	Home.	OM	Road	C-d	Ch.	Row tot.	Us. Ac.
A	58	3	0	0	0	0	0	23	3	0	0	0	0	0	11	0	0	0	0	98	0.592
P	1	0	0	2	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	4	0
Cof.	2	0	0	0	0	0	1	2	0	0	0	0	0	0	0	0	0	0	0	5	0
W-l	4	0	0	8	1	0	0	3	3	0	0	0	0	1	2	0	0	0	0	22	0.364
S-l	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0.500
T	3	0	0	0	0	6	0	4	0	0	0	0	0	0	0	0	1	0	0	14	0.429
Shr.	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Hed.	2	0	0	0	0	0	0	36	0	0	0	0	0	0	2	0	0	0	0	40	0.900
G-l	5	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	0
Riv.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wat.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
W-p	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Buil.	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	4	1
Sch.	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	1
Home.	6	0	0	1	0	0	0	0	0	0	0	0	0	0	9	0	0	0	0	16	0.563
OM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Road	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	2	0	0	4	0.500
C-d	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ch.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Col. tot.	83	3	0	12	4	6	1	69	7	0	0	0	4	2	24	0	3	0	0	**218**	
Prod. Ac.	0.699	0	0	0.667	0.250	1	0	0.522	0	0	0	0	1	0.500	0.375	0	0.667	0	0		

A=Annual crops, P=Perennial crops, Cof.=Coffee, W-l=Woodland, T=Tree(s), Shr.=Shrub(s), Hed.=Hedge(s), G-l=Grassland, Riv.=River, Wat.=Water, W-p=Water pond, Buil.=Building, Sch.=School Compound, Home.=Homestead Compound, OM=Open Market area, Road=Roads, C-d=Cattle dip area, Ch.=Church Compound

Hututu

	A	P	Cof.	W-l	S-l	T	Shr.	Hed.	G-l	Riv.	Wat.	W.p	Buil.	Sch.	Home.	OM	Road	C-d	Ch.	Row tot.	Us. Ac.
A	70	1	0	1	1	0	0	17	1	0	0	0	0	0	15	0	0	0	0	106	0.660
P	2	2	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0.333
Cof.	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	1
W-l	5	0	0	18	1	0	0	10	0	0	0	0	0	0	6	0	0	0	0	40	0.450
S-l	1	0	0	0	1	0	0	1	1	0	0	0	0	0	0	0	0	0	0	4	0.250
T	1	0	0	1	2	3	0	4	0	0	0	0	1	0	2	0	1	0	0	15	0.200
Shr.	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	2	0
Hed.	5	0	0	0	0	0	0	14	0	0	0	0	0	0	0	0	0	0	0	19	0.7368
G-l	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	1	0	0	3	0.3333
Riv.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wat.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
W-p	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Buil.	0	0	0	0	0	0	0	1	0	0	0	0	5	0	0	0	0	0	0	6	0.8333
Sch.	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	1
Home.	1	0	0	0	0	0	0	0	0	0	0	0	0	0	10	0	0	0	0	11	0.9091
OM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	4	1
Road	8	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	4	0	0	14	0.2857
C-d	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ch.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Col. tot.	94	3	3	21	8	3	0	47	3	0	0	0	7	1	33	4	7	0	0	**234**	
Prod. Ac.	0.745	0.667	1	0.857	0.125	1	0	0.298	0.333	0	0	0	0.714	1	0.303	1	0.571	0	0		

A=Annual crops, P=Perennial crops, Cof.=Coffee, W-l=Woodland, S-l=Shrubland, T=Tree(s), Shr.=Shrub(s), Hed.=Hedge(s), G-l=Grassland, Riv.=River, Wat.=Water, W-p=Water pond, Buil.=Building, Sch.=School Compound, Home.=Homestead Compound, OM=Open Market area, Road=Roads, C-d=Cattle dip area, Ch.=Church Compound

Sinoko

	A	P	Cof.	W-l	S-l	T	Shr.	Hed.	G-l	Riv.	Buil.	Sch.	Home.	OM	Road	C-d	Row tot.	Us. Ac.
A	57	5	0	1	0	3	0	39	2	0	0	0	19	0	1	0	127	0.4488
P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cof.	0	0	2	0	0	0	0	1	0	0	0	0	0	0	0	0	3	0.6667
W-l	3	0	0	15	0	0	0	12	3	0	0	0	2	0	0	0	35	0.4286
S-l	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
T	1	0	0	0	1	0	0	2	0	0	0	0	0	0	0	0	4	0
Shr.	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	1
Hed.	1	0	0	0	0	0	0	12	0	0	0	0	0	0	0	0	13	0.9231
G-l	2	1	0	1	0	0	0	1	2	0	0	0	0	0	0	0	7	0.2857
Riv.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Buil.	3	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	7	0.5714
Sch.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Home.	3	0	0	0	0	0	0	0	0	0	0	0	18	0	0	0	21	0.8571
OM	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	2	1
Road	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0
C-d	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Col. tot.	70	6	2	17	1	3	1	68	7	0	4	0	39	2	1	0	**221**	
Prod. Ac.	0.814	0	1	0.882	0	0	1	0.176	0.286	0	1	0	0.462	1	0	0		

A=Annual crops, P=Perennial crops, Cof.=Coffee, W-l=Woodland, T=Tree(s), Shr.=Shrub(s), Hed.=Hedge(s), G-l=Grassland, Riv.=River, Wat.=Water, W-p=Water pond, Buil.=Building, Sch.=School Compound, Home.=Homestead Compound, OM=Open Market area, Road=Roads, C-d=Cattle dip area, Ch.=Church Compound, Ind.=Industrial sites

Wehoya

	A	P	Cof.	W-l	S-l	T	Shr.	Hed.	G-l	Riv.	Wat.	W.p	Buil.	Sch.	Home.	OM	Road	C-d	Ch.	Ind.	Row tot.	Us. Ac.
A	72	5	2	0	0	1	0	43	5	0	0	0	1	1	13	0	2	0	0	0	145	0.497
P	2	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	4	0
Cof.	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	4	0.250
W-l	1	0	0	15	0	0	0	2	1	0	0	0	2	1	4	0	1	0	0	0	27	0.556
S-l	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
T	1	0	0	0	0	0	0	3	0	0	0	0	0	0	3	0	1	0	0	0	8	0
Shr.	1	0	0	2	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	4	0
Hed.	8	0	0	0	0	0	0	8	3	0	0	0	0	0	1	0	0	0	0	0	20	0.400
G-l	3	0	0	1	0	1	0	1	0	0	0	0	0	2	1	0	0	0	0	0	9	0
Riv.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wat.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
W-p	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Buil.	1	1	0	0	0	0	0	3	0	0	0	0	11	0	0	0	0	0	0	0	16	0.688
Sch.	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	2	0.500
Home.	6	0	0	1	0	0	0	0	0	0	0	0	0	0	21	0	0	0	0	0	28	0.750
OM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	4	1
Road	2	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	4	0.250
C-d	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ch.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ind.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Col. tot.	98	8	3	21	0	2	0	61	10	0	0	0	14	5	43	4	7	0	0	0	**276**	
Prod. Ac.	0.735	0	0.333	0.714	0	0	0	0.131	0	0	0	0	0.786	0.200	0.488	1	0.143	0	0	0		

A=Annual crops, P=Perennial crops, Cof.=Coffee, W-l=Woodland, S-l=Shrubland, T=Tree(s), Shr.=Shrub(s), Hed.=Hedge(s), G-l=Grassland, Riv.=River, Buil.=Building, Sch.=School Compound, Home.=Homestead Compound, OM=Open Market area, Road=Roads, C-d=Cattle dip area

Yuya

	A	P	Cof.	W-l	S-l	T	Shr.	Hed.	G-l	W-p	Buil.	Sch.	Home.	OM	Road	Ch.	Ind.	**Row tot.**	**Us. Ac.**
A	40	4	0	2	0	0	0	24	0	0	0	0	27	0	0	0	0	97	0.412
P	3	0	0	1	0	0	0	1	0	0	0	0	3	0	0	0	0	8	0
Cof.	0	0	5	0	0	0	0	3	0	0	0	0	1	0	1	0	0	10	0.500
W-l	2	1	0	10	0	0	0	6	0	0	0	0	2	0	0	0	0	21	0.476
S-l	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
T	1	0	1	0	0	1	0	3	0	0	0	0	2	0	0	0	0	8	0.125
Shr.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hed.	1	0	0	0	0	0	0	14	0	0	0	0	1	0	0	0	0	16	0.875
G-l	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
W-p	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Buil.	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	2	1
Sch.	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	2	1
Home.	3	0	0	0	0	0	0	0	0	0	0	0	10	0	1	0	0	14	0.714
OM	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	1
Road	1	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	3	0.333
Ch.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ind.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Col. tot.	51	5	6	13	0	1	0	51	0	0	2	2	47	1	3	0	0	**182**	
Prod. Ac.	0.784	0	0.833	0.769	0	1	0	0.275	0	0	1	1	0.213	1	0.333	0	0		

A=Annual crops, P=Perennial crops, Cof.=Coffee, W-l=Woodland, S-l=Shrubland, T=Tree(s), Shr.=Shrub(s), Hed.=Hedge(s), G-l=Grassland, W-p=Water pond, Buil.=Building, Sch.=School Compound, Home.=Homestead Compound, OM=Open Market area, Road=Roads, Ch.=Church Compound, Ind.=Industrial sites

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