Trends in land cover change of the greater Gaborone area: Implications for agricultural production loss

Master of Science (MSc) in Agricultural Engineering (Land Use Planning) stream

By
Osenotse Kephuthelotswe

June 2013

University of Botswana

Botswana College of Agriculture

Trends in land cover change of the greater Gaborone area: Implications for agricultural production loss

A dissertation submitted to the Department of Agricultural Engineering in partial fulfillment of the requirement for the degree of Master of Science (MSc) in Agricultural Engineering (Land Use Planning) stream

By

Osenotse Kephutheletswe (ID: 200400020)

June 2013

Main Supervisor: Prof. N. Batisani

Co - Supervisors:

Dr. M. Tapela

Mr. L. Akanyang

Department of Agricultural Engineering and Land Planning

University of Botswana

CERTIFICATION

Nnyaladzi Batisani Batisani 24-07-13

Main Supervisor's Name and Signature Date

Mataba Tapela 24/7/13

Co-Supervisor's Name and Signature Date

Lawrence Akanyang 24/7/13

Co-Supervisor's Name and Signature Date

Kethusegile Mmolawa 24/07/2013

Head of Department's Name and Signature Date

APPROVAL

Nyadadzi Batisani — 24-07-13

Main Supervisor's Name and Signature — Date

Mataba Tapela — 24/7/13

Co-Supervisor's Name and Signature — Date

Lawrence Akanyang — 24/7/13

Co-Supervisor's Name and Signature — Date

Khumoetsile Mmolawa — 24/07/2013

Head of Department's Name and Signature — Date

E B KHONGA — 24/07/2013

Dean of Faculty's Name and Signature — Date

STATEMENT OF ORIGINALITY

The work contained in this dissertation was compiled by the author at the University of Botswana between January 2011 and August 2012. It is original except where the references are made and it will not be submitted for the award of any other degree or diploma of any other University.

Author's Name and signature

24/07/2013

Date

ACKNOWLEDGEMENTS

I recognize the almighty GOD for his mercy and favor. He has given me the courage sufficient to walk over the challenges I encountered during my studies. I am earnestly thankful to my parents, Mrs. Reginah Kephutheletswe and the late Mr. Alphus. D. Kephutheletswe for motivating me. My sincere appreciation goes to Professor Nyaladzi Jay Batisani, my supervisor for his continued guidance and unreserved support through the entire Master's program. The support I got from Dr. Mataba Tapela, Mr. Lawrence Akanyang and Mr. Reuben Sebego is appreciated for their valuable input in GIS matters. Dr. Rejoice Tsheko is also appreciated for the insightful remote sensing lessons.

Professor Bennedict Kayombo is appreciated for his coordination of the MSc program. A special thank you goes to Dr. Gilbert Gaboutloloe, his passion for his work has inspired me to do my best. My acknowledgment also goes to Mr. G. Mantu, Mr J. Makoyi, and all the AEL department staff, your involvement made a difference especially during course work in laboratory and field practicals. I am grateful to my colleagues for their thought-provoking lecture dialogues throughout the entire coursework period. The following people are also appreciated for their assistance and above all for believing in me, Ms. Patricia Dihutso, Tshepo Marape and Florence Tembo. Lastly I would like to thank my family for their all-time love and support. To my brothers Lopang, Tafila, Makamu and Ndiupi I hope this will encourage you to accomplish your dreams.

ABSTRACT

Peri urban areas are contiguous to urban areas, they consist of a large population and these are regions where farming practice is in conflict with other economic activities. These activities drive the changes in land cover that end up constricting the availability of natural resources for human and livestock use, some of these changes pose environmental risks. Hence this study was aimed at understanding the dynamics of land cover of the greater Gaborone area, and the impacts these changes have on agricultural production. Land cover change of the greater Gaborone area was analyzed using an orthophoto for the year 2002 and a satellite image from Google Earth map (acquired 8th June 2010 through spot platform).Population data was also linked to land cover changes. Yield data was used to estimate production loss consequent to land cover changes. There has been a decline in the agricultural lands while the built environment increased. Rangeland decreased from 698.12 km^{2}to 674.46 km^2, arable lands from 137.34 km^2 to 100.20 km^2 whereas the buildup area increased from 81.09 km^2 to 144.09 km^2 from 2002 to 2010.Amid these changes, 44.08 km^2 and 9.00 km^2 of rangeland and arable land respectively have been converted to build up area resulting in yield losses of 980 LSU and 142 200 Kg of cereal. Fiscally these losses amounted to P 101 738 70 and P 337 014 worth of livestock and cereal respectively. During the same period, population in the study area has been increasing from 253 874, 356·251 in 2001, 2011 respectively and predictably 699 409 in 2035. Weighed against the buildup area, these inhabitants necessitate81.09 km^2, 144.09 km^2 and the predicted 282.54 km^2 of build environment in the same years. From 2002 to 2010 most of the rangeland and arable lands were converted to build up areas. The increase in buildup environment is undoubtedly at the expense of rangeland and arable land.

Key words: Urban expansion, agricultural land loss, subsistence farmer, food self sufficiency, Botswana

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

APPENDICES

ACRONYMS AND ABBREVIATIONS

BRIMP	Botswana Range Inventory Monitoring Project
CSO	Central Statistics Office of Botswana
EPA	United States Environmental Protection Agency
FAO	Food and Agriculture Organization of the United Nations
GECAFS	Global Environmental Change and Food Systems
GIS	Geographical Information System
IIED	International Institute for Environment and Development
LSU	Livestock Unit/s
LUCC	Land use/cover change
LUCID	Land use change impacts and dynamics
MoA	Ministry of Agriculture, Botswana
RS	Remote sensing
STEPS Sustainability	Social, Technological and Environmental Pathways to
UNEP	United Nations Environment Programme

CHAPTER ONE

1.0: INTRODUCTION

It is projected worldwide that more than five billion people will live in urban areas by the year 2025 with majority (80%) of these living in cities and towns in developing countries (ITC, 2005). Thus concerns relating to land use/cover change (LUCC) have invoked interest amongst scholars, as well as international organizations, ranging from those who attempt to model spatial and temporal patterns of land conversion to those who want to comprehend the causes and effects of LUCC and how these effects can be averted (LUCID, 2004; GECAFS, 2005; Long et al, 2008; Araya, 2009 and FAO, 2011).

The development process of urbanization drives the change in LUCC pattern, which may also have adverse impacts on the environs of the area (Agarwal et al, 2002; Wu et al, 2008 and Jat et al, 2008). LUCC limit the obtainability and accessibility of different biophysical resources including arable land, rangeland, vegetation, water and other resources. Subsequently, LUCC could lead to a diminished availability of varying products and services for human use, livestock, agricultural production and also harm the environment. (Gwebu, 2004; Wu et al, 2008 and Soffianian et al, 2010).

Swift urban expansion in various conurbations of developing countries has been identified as a major cause of LUCC (Weng, 2002 and Codjoe, 2007). With amassed recognition of urbanization as a cause of LUCC, essential and dependable data are mandatory to observe, investigate and envisage current and imminent trends of LUCC consequential from the urban growth. Urban expansion monitoring and mapping hence befits the necessity to make comprehensive policy for development and regulation of further growth of urban areas. Such tasks entail the use of reliable data on regular bases.

Remote sensing techniques (RS) and geographic information systems (GIS) have become important tools in the acquisition, monitoring, evaluation and mapping of urban expansion and LUCC.LUCC maps produced through the use of RS and GIS provides basis for reliable data in urban growth studies. Through the use of RS imagery and GIS, LUCC data is generated for storage, quantifying, modeling and analyzing spatial data (Reis, 2008; Njungbwen and Njungbwen, 2011 and Makhamrehand Almanasyeh, 2011). LUCC analysis may contribute to a broad perspective of changes that have environmental and socio - economic impacts, and provide relevant and precise information for comprehensive policy and decision making in land use planning approaches at local and regional levels (Long et al, 2008; Oladele and oladimeji, 2011).

In the context of peri – urban development, LUCC has of recent attracted the attention of researchers (Adell, 1999; Allen, 2003; and Mandere, 2010). Allenet al (1999) describes the peri–urban expanse as a 'transitional area between urban and rural zones, being thus a special case of urban-rural relations'. Mandere (2010) clarifies the peri urban areas to be 'areas which are transitioning between the urban and rural landscapes as determined by daily commuting to central business districts of the nearby city or town'. In addition the peri urban areas as described by Busck et al (2006) are regions contiguous to urban areas (built up areas) consisting of a large population, furthermore these are regions where farming practice is in conflict with other economic activities for example, commercial, residential and recreational interests.

1.1: Rationale

The peri- urban interface has only emerged recently as research focus independent from urban and rural studies (Adell, 1999; Allen et al 1999 and Allen, 2003). Moreover land cover change in peri-urban areas associated with urbanization is discussed in general terms on large regional scales (Pickett et al 2001; Lambin et al 2003; Huston 2005 and Simon et al 2006). This research uses the Gaborone city as a case study to provide a perspective of land cover changes associated with urbanization that are more scale-appropriate for land management and conservation efforts.

Thus the study would provide pertinent information to contribute in the environmental management plans and improve urban planning issues through: provision of information on the dynamics of urban land use of the study area. The study would also assist planners and environmentalists and decision makers to consider the potential of geospatial tools to monitor and plan for urban environments. It will also provide a baseline for further research by identifying topics that should be dealt with in much more detail in the study area.

1.2: Problem statement

The growth of Gaborone city has necessitated infringement on surrounding communal farmlands. The capital city is still spreading out and suggestions of acquiring more farmland to accommodate urban developments have been mentioned by authorities. The conversion of agricultural land has an impact on agricultural production and eventually food security of the surrounding rural communities (Mosha and Cavric, 2001).

Government policies like, the Tribal Grazing Land Policy of 1975, the National agricultural policy of 1991 and the National Master Plan for Arable Agriculture and Dairy Development (NAMPAAD) advocate for the conservation of scarce agricultural and land resources (CAR, 2005). Even though such policies are in place, it has not been possible to prevent conversion of agricultural land to other uses specifically to build up area. The conversions are influenced by chiefly among other factors, the high demand for land for residential uses within Gaborone city

(Batisani and Yarnal, 2010).To curb the conversion of land, the government has of late taken a stern measure to maintain land use zones as planned and approved. The Department of Town and Regional Planning (DTRP) through the Town and Country Planning Act is mandated to prepare and gazette development plans in all planning areas. Even though that is the case the plans are reviewed from time to time to accommodate the practical needs of the people (GoB, 1980).

Based on the above, the goal of this study is to better understand the dynamics and temporal differences of land cover transitions in peri-urban areas of the Greater Gaborone area.

The specific objectives are to;

(i) Characterize land cover transformations in the greater Gaborone area between 2002 and 2010.

(ii) Relate land cover transformations to population growth in the study area.

(iii) Quantify relationships between urban expansion and loss in agricultural production.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

Land use/cover change is a physical, biological and chemical process which is linked to the way human beings manage the land (Wu et al, 2008). Land use/ cover change involves two definitions of conversion and modification. Land cover conversion involves a change from one cover type to another for example from grass to tree cover. Land use change may include conversion from one land use to the other for example, from grazing to cropping, agricultural to residential land or settlements (Quentin et al, 2006). Land cover modification involves alterations in terms of structure or function of land cover but without a whole change form one type to the other, for example a change in productivity (Briassoulis, 1999). Land use change may take the form of modification of a certain type of land use and this involves changes in the intensity of that use for example, changes of forests to recreational sites and residential areas changing from low income to high income (Meyer and Turner, 1996).

Land cover is the attributes of the earth's land surface, its biophysical state, also include human activities like settlements, fields and mines (Lambin et al, 2003). The causes of LUCC are categorized into proximate and underlying causes. The proximate or direct causes of land use and cover change constitute human activities or actions that originate from planned and envisioned land use that eventually affect land cover (Ojima et al, 1994).

The proximate causes of LUCC are forces that operate from far afield and yet can change or alter the proximate causes (Leemans et al, 2003). While proximate causes operate at local level, farm, households and communities, the underlying causes are driven by social, political, economic, demographic, technological, cultural and biophysical variables in the relationship between human beings and their environment and may be found to be emanating from regional and international levels (Lambin et al, 2003).

Food security materializes when all people at all times have access to adequate food that is affordable, safe and healthy, is culturally acceptable, meets specific dietary needs, is obtained in a dignified manner and is produced in ways that are environmentally sound and socially just (FAO, 1996). Food security is dependent on the food systems, when food systems are stressed; food security is likely to diminish. Food systems are interactions between and within bio-geographical and human environments that results in the production, processing, distribution, preparation and consumption of food (GECAFS, 2005).

The components of a food system are food availability (production, distribution and exchange), food access (affordability, allocation and preference), and food utilization (nutritional value, social value and food safety).

Human alteration of land through urbanization affects the ability of the land to support needed food production. Land use changes affect the capacity of the land to generate sufficient food supplies. Losses of arable land to infrastructure development might lead to food production deficit in the future. The possible risks of land use change are not only environmental but also include social risks. One of the social risks that is brought about by land use change is the impact on food security, as developments take place they threaten to compete for arable lands that could be suitable for agricultural food crops resulting in the potential threat of driving down potential supply (UNEP, 2009). Greater emphasis should be placed on the conservation of land, water, plant and animal resources. Land use planning is to be intensified to tackle the problems of land degradation, loss of agricultural biodiversity and soil erosion and maintaining high productivity levels (Emerson and Wallis, 2003).

The convention to combat desertification of 2008 supports that land use changes should be considered where current agricultural patterns are no longer sustainable. Conversions of marginal agricultural lands into suitable alternatives would prevent land degradation and will regenerate long term farming potential. The introduction of measures to limit the conversion of agricultural land to other uses that are not agriculturally viable will maintain a reserve of land for food production at the same time prohibiting the encroachment of urban and rural residential development into food producing lands.

2.2 Urban expansion and land use/land cover change

Urbanization is the result of increasing population in urban areas relatively and absolutely. The driving forces of urbanization are the perceived quality of life differentials between urban and rural areas that is jobs, living conditions and better services. Urbanization is linked to urban expansion which is also known as urban sprawl.

Urban sprawl and urbanization has brought about environmental problems which are faced by almost all the cities around the world (Makhamreh and Almanasyeh, 2011).

The conversion of agricultural land and forest as well as wetlands for urban infrastructural development is linked to the widespread removal of vegetation to support the urban needs which puts pressure on the nearby areas which may be ecologically sensitive. There is also the problem of improper waste disposal and handling, air and water pollution and loss of productivity by workers as they spend many hours in traffic congestion (Ujoh et al, 2010).

2.3 LUCC in peri-urban areas in developing countries; implications for food security

Peri-urban refers to the geographical edge of a city and marks the transition or interface between rural and urban activities. Peri-urban areas are characterized by an increasing population density, uncontrolled conversions of farmlands to housing, lack of regulation, diverse sources of income and intensified resource exploitation (Marshall et al, 2009).

Even though urbanization brings about opportunities, it has resulted in concentrating poverty and environmental degradation in peri-urban areas and the peri-urban poor are often the most affected (Allen et al, 2006). Seemingly so, subsistence farming is considered to be a system of an economy truncated households, this implying that majority of households have small proceeds also that the proceeds are derived from agricultural undertakings (d' Allonnes, 2006).

The practice of agriculture in urban areas takes place at the city's periphery where its recognition is little, this recognition is due to the fact that the peri-urban interface is viewed as a temporary place on the city's fringes which will soon pave way for urban development (Adedeji and Ademiluyi, 2009).Peri-urban agriculture is also disadvantaged by lack of judicious proceedings as it occurs outside the boundaries of civic authorities, there is therefore deprioritisation by agricultural programs.

Botswana as a developing country is faced with a number of land issues particularly in its cities and towns. Population and economic growth has exerted vast pressure on land. Although existing legal frame work is in place, it has not been an easy task to equitably distribute land among the people for different uses (Ministry of Lands, 2002).Land institutions especially the land boards have from time to time been criticized for the cumbersome and time consuming processes and procedures of allocating land. These complaints are a reflection that there is pressure resulting from the socio economic needs of the people (Tembo and Manisa, 2001).

Illegal transfer of land has been another issue of concern. The requirements for land transfer are that the land has to be developed for the purpose it was applied for, however land holders have been found to be ignorant of these requirements and transferred undeveloped land. The transfers are done to those who have the ability to buy land as compared to the poor who actually need it. This development creates a skewed distribution of the land (Mathuba, 2003).

The growing population has created land use conflicts as land is now required for many uses. As a result some land uses have been pushed to marginal areas.

Settlements have been expanding into arable land; arable farms into livestock rearing areas and livestock rearing into wildlife areas. These land use conflicts have been found to be putting pressure on land resources with rangelands being the most affected. At the fringes of cities and towns, pastoral residents want to rear cattle whereas the grazing resources are hastily lessening (Ministry of Lands, 2002).

Even though the government has responded to the migration of people into towns and cities (especially Gaborone) by decentralizing services through the National Settlement Policy, rural dwellers continue to move to towns. The villages close to Gaborone (Mogoditshane, Metsimothlabe, Tlokweng, Gabane and Mmopane) continue to grow in terms of population. The population of Gaborone and its pace of urbanization has created problems of its expansion into arable land, illegal dumping of waste in its outskirt villages leading to land degradation. Other issues consequent to its urbanization have been the illegal mining of sand, quarrying activities and unauthorized land use changes (GoB, 1992).

Land use/Cover Change detection

Change detection studies involving the use of satellite image data has been done using a large range of methodologies for identifying land use/cover changes (Mas, 2000). The methods have some advantages as well as disadvantages.

Image differencing – image differencing is a commonly used method which involves the subtraction of registered images acquired at different times. The subtraction is either pixel by pixel or band by band. A pixel value of 0 signifies no changes whereas change is represented by a negative or a positive value (Lu et al, 2004). Even though this method is not complex its challenge is to identify the threshold values of change and no change in the final or resultant images.

Image rationing – Its simplicity and challenges are comparable to image differencing, the difference between the two is that image rationing is not as commonly used as the image differencing method. This method is simply a ratio of the images acquired at different times, pixel by pixel and band by band (Berberoglu and Akin, 2009). Changes are represented by pixel values of more or less than one whereas pixel values of one represent no change.

Post classification –Post classification is widely used and is easy to understand. The principle of the method is that two images acquired at different times are independently classified and then compared. Changes between the two images are visualized by the use of a change matrix indicating the amount of changes that have occurred for both dates (Briassoulis, 1999).Through the matrix it is easy to see what changes occurred and in which class the changes occurred. The advantage of this method is the negligible impacts of radiometric and geometric differences between the two images (Berberoglu and Akin, 2009).

Multi date classification – Multi date images are combined into a single dataset in which either supervised or unsupervised classification is performed. Areas where changes have occurred will be represented by different statistics as compared to those with no changes (Pontius et al, 2011).This method produces multiple classes with respect to the spectral changes thus the interpretation of the results is often complex requiring a good knowledge of the study area (Lu et al, 2004).

Change vector analysis – This technique is based on the spatial representation of change in spectral space. Change here is represented by a vector defined by two factors which are the direction of change and the magnitude of change. Under this method, multiple bands can be processed however the difficulty is in determining the threshold of magnitude and in differentiating between change and no change. Often the interpretation of the direction vector is not easy (Coppin et al, 2004).

Image regression – Image regression method assumes the existence of a linear relationship between pixel values of the same image at different times (Atasoy et al, 2006).A regression function best describing the pixel relationship is developed, the residuals from the regression function are deemed to represent areas of change. Through this method there are minimal radiometric impacts however there is difficulty in selecting the appropriate regression function and in defining the threshold between change and no changes (Rogana et al, 2004).

Various as they are, the alternative to use either of them is dependent on the ability of the user to successfully execute them and arrive at desired and understandable results. Analysis involving large data or many images acquired at different times may also prompt for the use of certain techniques over others.

CHAPTER THREE

METHODOLOGY

3.1 Description of the study area

The study area is the greater Gaborone area, which encompasses the localities of Gaborone city and the peri urban villages of Mogoditshane, Tlokweng, Gabane, Metsimotlhabe and Mmopane (Figure 3.1). Gaborone city has experienced economic growth and development and is among the fastest growing cities in sub Saharan Africa. The city's population has created problems with resources more importantly land (Batisani and Yarnal, 2010).

Hence Gaborone city is surrounded by tribal and private agricultural land on the northern, eastern and southern sides. The migration of people into the city in search for employment has further created problems of competition for land among tribal lands and agriculture. The projected population for Gaborone city is 313 000 by 2030 (CSO, 2001). This population and the envisaged growth of the greater Gaborone together with urban sprawl could result in with much of the scarce fertile agricultural land being taken up by settlement growth and only leaving poor unproductive soils.

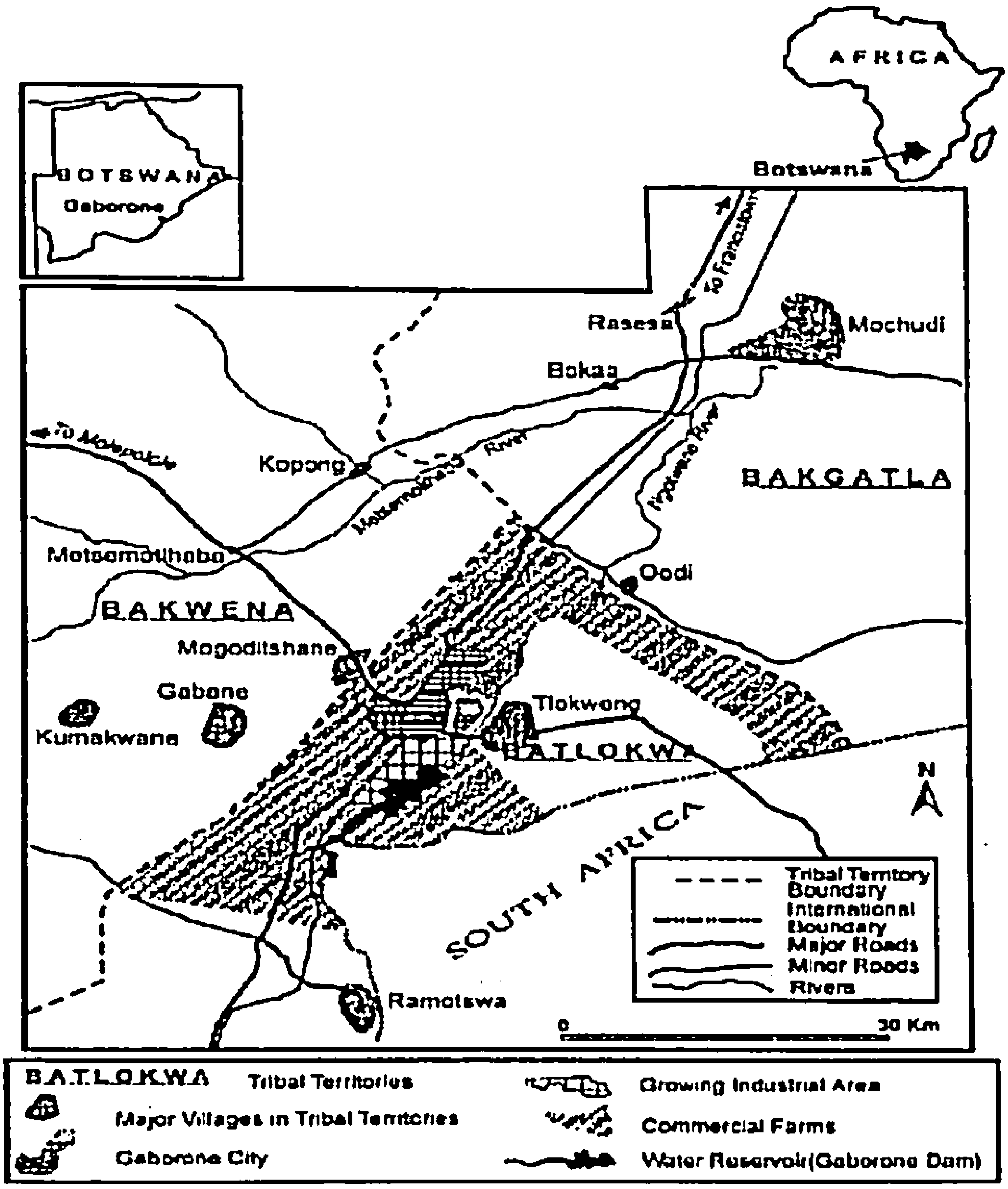

Figure 3.1: Greater Gaborone area and its location (Nkambwe and Totolo, 2005)

3.2 Data

Land cover patterns for 2002 were mapped by the use of an orthophoto from the department of surveys and mapping. This orthophoto is projected to UTM (WGS_84 Zone 35 S), with a geographic extent of 7294783.37 m North, 415270.34 m West, 7254648.39 m South and 369825.69 m East. Its spatial resolution was 1:1. Tiff images from Google map (acquired June 8th 2010 through spot platform http://maps.google.com) were used as an image to complement the orthophoto. The image also covered the same extent and resolution as that of the orthophoto.

The population and housing census preliminary results for the Gaborone and the villages that form the greater Gaborone were used. This data was obtained from the central statistics office. The yield per hectare (kg/ha) of cereal crops (maize) for the Gaborone region is 158 kg/ha (CSO, 2006) while the livestock carrying capacity is between 4 and 5 ha/lsu (averaging to 4.5 ha/Lsu) (MoA, 2001). Supplementary data included the BMC price structure by grade of P 23.07/Kg (Appendix 1) and the BAMB cereal (maize) price of P 118.00/50 Kg bag (Appendix 2).

3.3 Data Analysis

The orthophoto was used as a base map while the satellite image was used as a warp image (or the image to be analyzed for changes). Land cover types were manually digitized and include: (1) Urban or build up area, (2) arable land, (3) rangeland, (5) tree dominated and (5) water. Population data for the census year of 2001 and 2011 was also related to urban growth pattern. Furthermore arable and rangeland converted to the built environment was analyzed in terms of potential yield loss.

3.3.1 Geo referencing and mosaicking

Screen captures (tiff images) of the 2010 SPOT satellite image from Google map were geo referenced (image to image geo referencing), the first order polynomial (affine) method was used as a warping method as it enables for accurate results because the warp image will only shift its origin, scale, and rotates to merge that of the base (Tufts university, 2007). The tiff images were then put together to make a single image by mosaicking, and by default when displayed in the same data frame as that of the base map, the warp image assumes the same projection (Tufts university, 2007). The 2010 satellite image was therefore projected to UTM (WGS_84 Zone 35 S) to match the spatial reference of the 2002 orthophoto. The geo referencing procedure followed is summarized in figure 3.2 below.

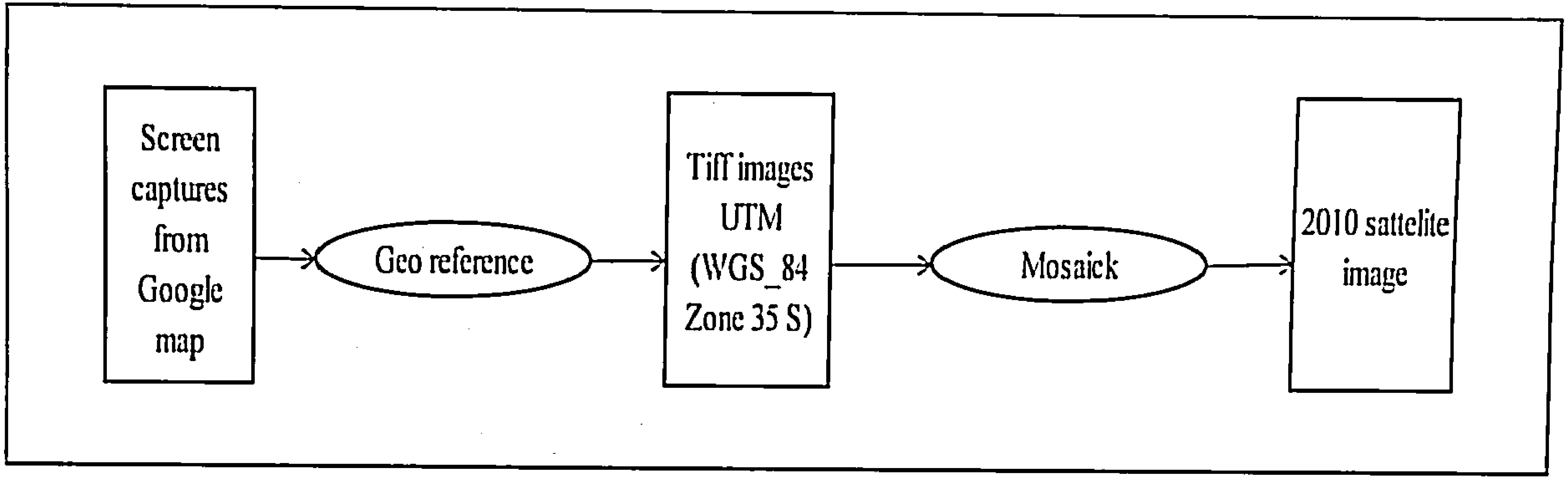

Figure 3.2: Flowchart for 2010 image processing

3.3.2Land cover classification scheme.

Urbanized areas exhibit spatially varied features making discrimination of some features a challenge (Anderson et al, 2001), hence land use/cover was categorized into five classes and their descriptions are given in Table 3.1. In this case, rangelands are the features that can be utilized by livestock for grazing and the "Build up/urban area" comprises all forms of built structure including, residential, transportation, commercial, industrial, facilities and other impervious features. Accuracy of the images was assessed by the use of a contingency table (Table 3.2)

Table 3.1: Land cover classification scheme

Land use/cover classes	Description
Rangeland	Areas that can be used for grazing livestock and any feature other than arable land, build up area, tree dominated, water body and 'others'. (Hills were only classed for their prominence, but are part of the rangeland)
Arable land	Land utilized for growing crops mainly under rain fed production for Subsistence farming
Build up/Urban area	Residential, transportation, commercial, industrial , facilities and impervious features
Tree dominated	tree and shrub
Water body	Dams and streams
Others	Un classified

Table 3.2: Contingency matrix for accuracy Assessment

Reference Data								
Classified Data	Rangeland	Arable land	Built up/Urban area	Tree dominated	Water Body	Others	Total	User's Accuracy
Rangeland	652	22	0	10	0	0	684	95 %
Arable land	2	99	0	4	0	0	105	94 %
Built up/Urban area	44	9	81	0	0	0	134	31 %
Tree dominated	0	0	0	13	0	0	13	100 %
Water Body	0	0	0	0	16	0	16	100 %
Others	0	0	0	0	0	9	9	100 %
Total	698	130	81	27	16	9	961	
Producer's Accuracy	93 %	76 %	100 %	48 %	100%	100 %		

$$\kappa = \frac{N\sum_{i=1}^{r} x_{ii} - \sum_{i=1}^{r}(x_{i+} \times x_{+i})}{N^2 - \sum_{i=1}^{r}(x_{i+} \times x_{+i})}$$

N is the total number of sites in the matrix, r is the number of rows in the matrix, χ_{ii} is the number in column i and row i, χ_{+i} is the total for row i and χ_{i+} is the total for column i (Jenson 1996). Kappa for the above matrix therefore is:

κ = [961 x (652 + 99 + 81 + 13 + 16 + 9)] – [(684x698) + (105x130) + (143x81) +(13x27) + (16x16) +(9x9)] / 961^2 – (684x698) + (105x130) + (143x81) + (13x27) + (16x16) + (9x9)

= 3 327 17/4 201 68

κ = 0.79

3.3.3 Characterization of land use/cover of the greater Gaborone area

Both the 2002 orthophoto and the 2010 image were manually delineated or digitized into polygons representing the land cover categories. The digitized orthophoto and image were then clipped to the boundary of the greater Gaborone; clipping demarcates the spatial extent of the area or region to be analyzed for LUCC. The 2002 and 2010 land cover maps were thus created. The extent of each land cover category was calculated in Arc Map 10 with the help of the spatial statistical tool (›› utilities ›› calculate areas).The results (areas) (Appendix 3 and 4) were tabulated. Figure 3.3 is an illustration of the land cover characterization procedure undertaken.

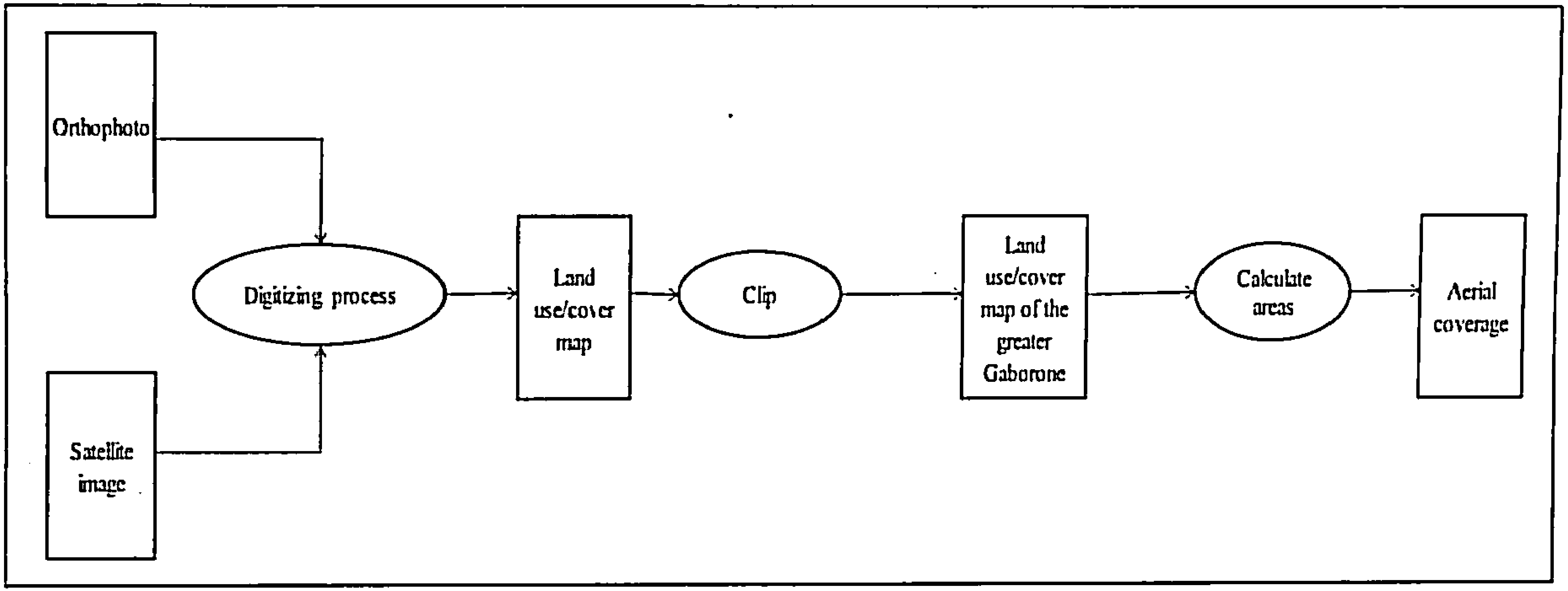

Figure 3.3: Land cover characterization procedure undertaken

3.3.4 Land cover change detection analysis

An overlay analysis (›› intersection) of the 2002 and 2010 land cover maps categories (polygons) was performed dual at a time and the areas of the intersected regions were calculated by the spatial statistical tool (›› utilities ›› calculate areas). The steps undertaken for the analysis are outlined in Figure 3.4.

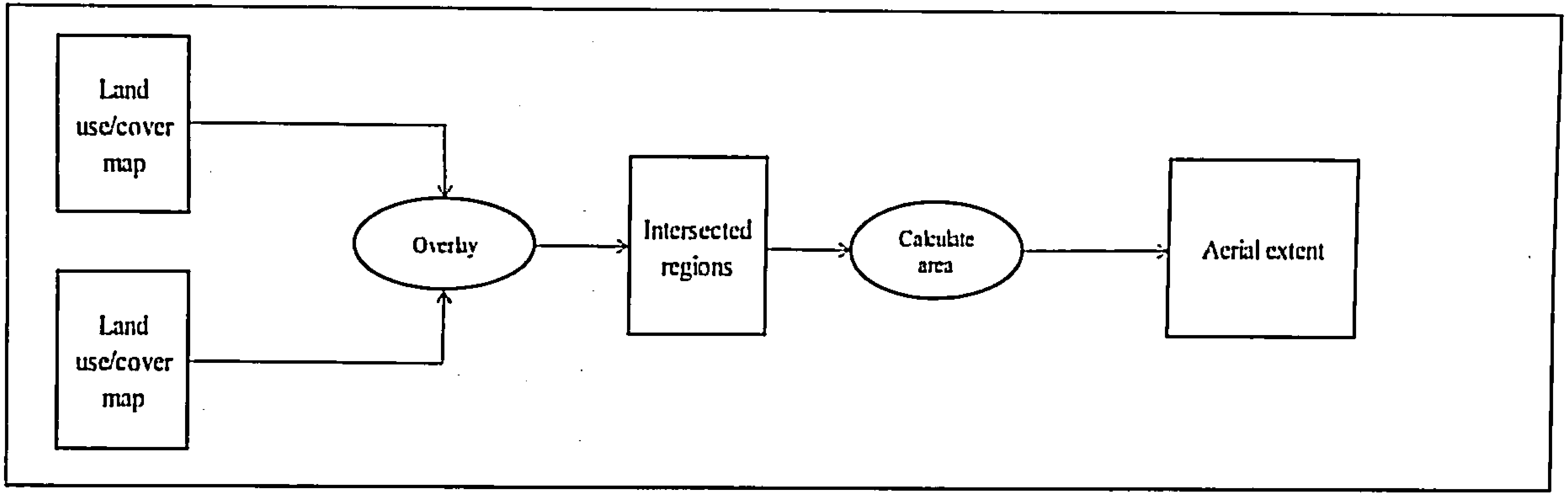

Figure 3.4: Land cover change detection analysis

Land cover is expected to change from one category to the other, from period one to period two (Wu et al, 2008). The intersected areal extents were thus used to analyze the land cover conversions from one class to another from 2002 to 2010 in a change matrix by the following equation; (Long et al, 2008 and Wu et al, 2008).

$$CHi = (pi.-p.i) / p.i \times 100 \qquad (1)$$

Where:

CHi is the change of land cover in row i relative to the previous compared year;

$pi.$ is the row total of grid cells for category i;

$p.i$ is the column total of grid cells for category i.

3.3.5Urban expansion detection

Build up /urban area maps were extracted from the land cover maps for the two periods (2002 and 2010). The extracted maps were rasterized and map subtraction was performed resulting in a buildup/urban area change map. Figure 3.4 depicts this process.

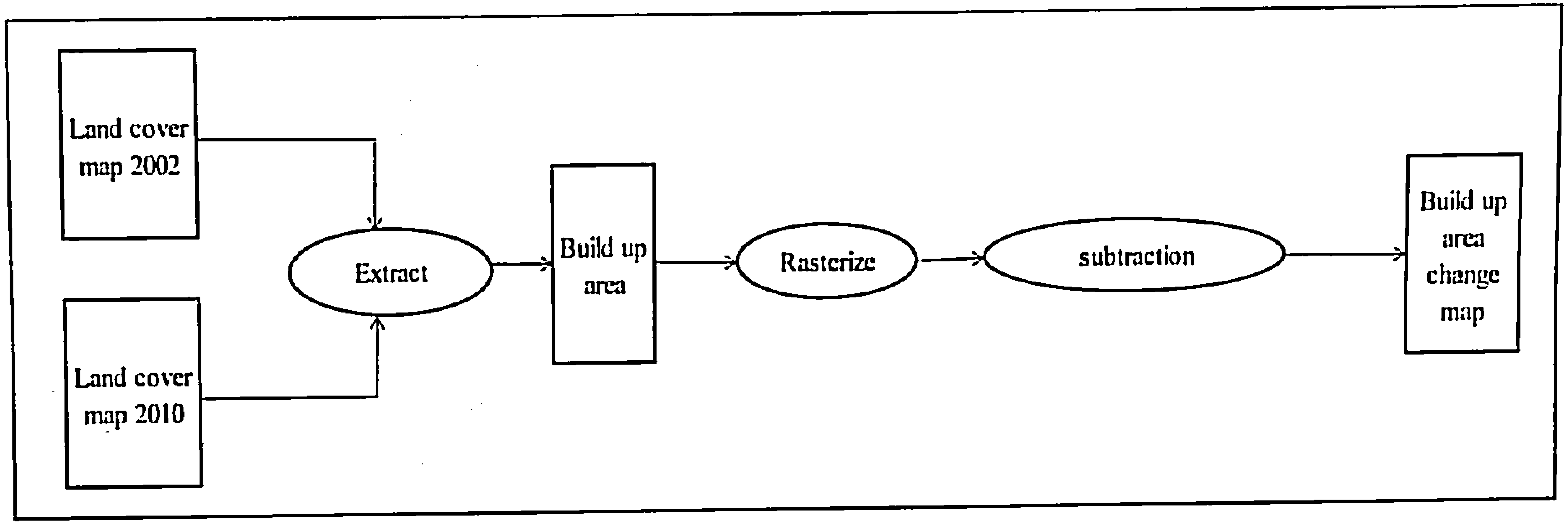

Figure 3.5: Urban expansion detection

3.4 Probable relationship between land cover change and subsistence farmer food self-sufficiency

3.4.1 Yield loss (LSU)

The quantity of grazing land (rangeland) converted to build up areas consequently resulted in yield loss (livestock units). The number of livestock units lost was calculated by the equation below;

$$\text{Yield loss (LSU)} = \frac{\text{Rangeland area}}{\text{Hlsu}} \quad \text{(at time } t_1 \text{ to time } t_0\text{)} \qquad (2)$$

Where;

Rangeland area is the size of the rangeland in hectares, converted to build up area

Hlsu is hectares per livestock unit (stocking rate)

The total number of cattle lost consequent to the conversion of rangeland to build up area was then calculated using the livestock unit ratio provided by d'Allonnes, (2006);

$$1 \text{ LSU} = 1 \text{ Cow of } 450 \text{ Kg} \qquad (3)$$

Botswana Meat Commission's price per Kg and LSU live weight of 450 Kg was then used to compute the price value for one cow (450Kg);

$$P = XY; \tag{4}$$

Where;

P is the amount in Pula for 1 cow;

X is the LSU live weight;

Y is the BMC price per Kg

The amount in pula was then multiplied by the number of cattle forfeited to deduce the fiscal value for cattle loss and consequently loss to subsistence communal farmers;

$$M = NP \tag{5}$$

Where;

M is the monetary value for cattle loss;

N is the number of cattle forfeited in the study area;

P is the price for 1(one) cow

3.4.2 Yield loss (Cereal)

The loss of land for cereal production to build up/urban area subsequently lead to cereal yield forfeited (Kg of cereal). Yield forfeited was calculated by the following equation;

$$\text{Yield loss (Kg of cereal)} = \frac{\text{Arable Area}}{\text{Kg/ha}} \quad \text{(at time } t_1 \text{ to time } t_0\text{)} \qquad (6)$$

Where;

Arable Area is the extent of arable land, in hectares converted to build up/urban area

Kg/ha is kilograms per hectare of maize (158 Kg/ha)

Cereal yield loss was then totaled by 50 kg bags that would have been lost due to arable fields converted to build up area and total number of 50 Kg bags and the BAMB producer price of P118.00/50Kg bag were used to estimate the monetary value lost due to arable land conversion by the following ratio analysis;

$f = pg$;

Where;

f is the fiscal value of the total number of bags forfeited;

p is the BAMB price of cereal per 50 Kg bag;

g is the total number of bags forfeited;

3.5Relating population to urban expansion in the Greater Gaborone area

The population for Gaborone and villages that constitute the greater Gaborone area are presented in Table 3.2. As population census in Botswana is held every after 10 years, the census for 2001 and 2011 and also growth rate were used to link population to build up area increase between 2002 and 2010

Therefore future urban expansion was then predicted by simple ratio analysis using annual population growth rates.

Table 3.3: Greater Gaborone population (2001 and 2011)

Name of locality	Years		Annual % growth (2001-2011)
	2001	2011	
Gaborone	186 007	233 135	2.03
Mogoditshane	32 843	57 637	5.79
Tlokweng	21 113	35 982	5.47
Gabane	10 399	14 842	3.62
Metsimotlhabe	4 056	8 081	7.14
Mmopane	3 512	14 655	15.36

Adapted from CSO preliminary results 2011

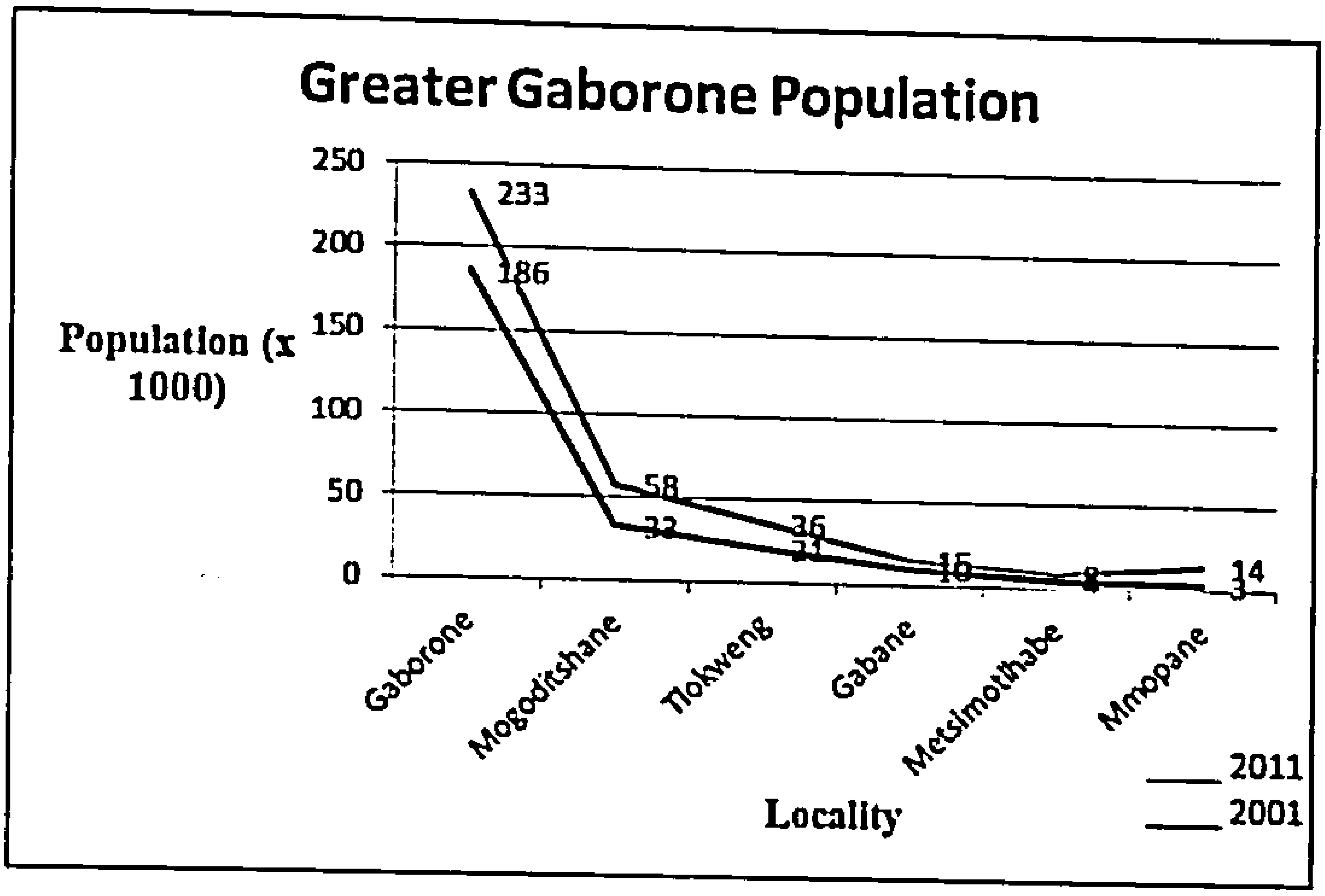

Figure 3.6 Population of the Greater Gaborone (2001 and 2011)

$r\beta + P$ (7)

Where;

r is the annual growth rate in % (2001 -2011);

β is the number of years (2011 – 2035, 2035 inclusive thus 25 years);

P is the population for the preceding census year

The following quotient was used for predicting the potential built up area in 2035.The predictions are done on the bases that the prevailing conditions stay the same;

$$\rho = \frac{\beta\,\alpha}{\sigma}$$

(8)

Where;

is the predicted build up area;

is the buildup area for the preceding year;

is the predicted population for the census year;

is the population for the preceding year,

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Characterization of land cover of the greater Gaborone area

Land cover maps for 2002 and 2010 are presented in Figure 4.2 and 4.3 respectively. In 2002 the greater Gaborone covered an area of 961.26 $km^2$with rangeland having an area of 698.12 km^2 and 674.46 km^2 in 2002 and 2010 respectively. Agricultural land (rangeland and arable land) have been decreasing. Rangeland displayed a relative decrease of 23.66 km^2 (2.4%) while arable land decreased by 3.9% for the same period. In 2002, built up/ urban area had a coverage area of 81.09 km^2 and 144.09 km^2in 2010, an increase of 63 km^2 (6.5 %) (Table 4.1).

Agricultural lands are declining while the built environment is increasing. This relationship has been found to be prevailing in most urban/peri urban research studies, Oladele and Oladimeji (2011) found agricultural lands in Ibadan, Nigeria to have decreased by 67.9% being replaced by construction between 1986 and 2000, while at the same time farmers were losing their lands to urban developments. This trend has been found to have resulted in acute food shortage to the urban population of Ibadan.

Similarly in a study done in Kathmandu Nepal, cultivated lands have been decreasing, from 39.10 km^2 in 1989 to 17.30 km^2 in 2009. Whereas the built environment increased from 17.70 km^2 to 43.10 km^2 between the same period (Rimal, 2011). Nonetheless a decline in agricultural lands is likely to impact agricultural production.

Table 4.1: Land cover statistic for the greater Gaborone (2002 and 2010)

Land cover category	Area Coverage in				Relative change in	
	km^2	per cent	km^2	per cent	km^2	per cent
	2002		2010			
Rangeland	698.12	72.6	674.46	70.2	-23.66	-2.4
Built up area	81.09	8.4	144.09	14.9	+63.00	+6.5
Arable land	137.34	14.3	100.20	10.4	-37.14	-3.9
Water body	16.32	1.7	16.32	1.7	0.00	0.00
Tree dominated	27.50	2.9	13.64	1.4	-13.86	-1.5
Others	0.91	0.1	13.49	1.4	+12.58	+1.3
Total	961.26	100	961.26	100		

In 2002 rangeland was the dominant land cover followed by arable land; build up areas, water body, forest cover and others. While in 2010 rangeland was still the most land cover but buildup area was now the second followed by arable land, water body and others (Figures 4.1, 4.2 and 4.3).

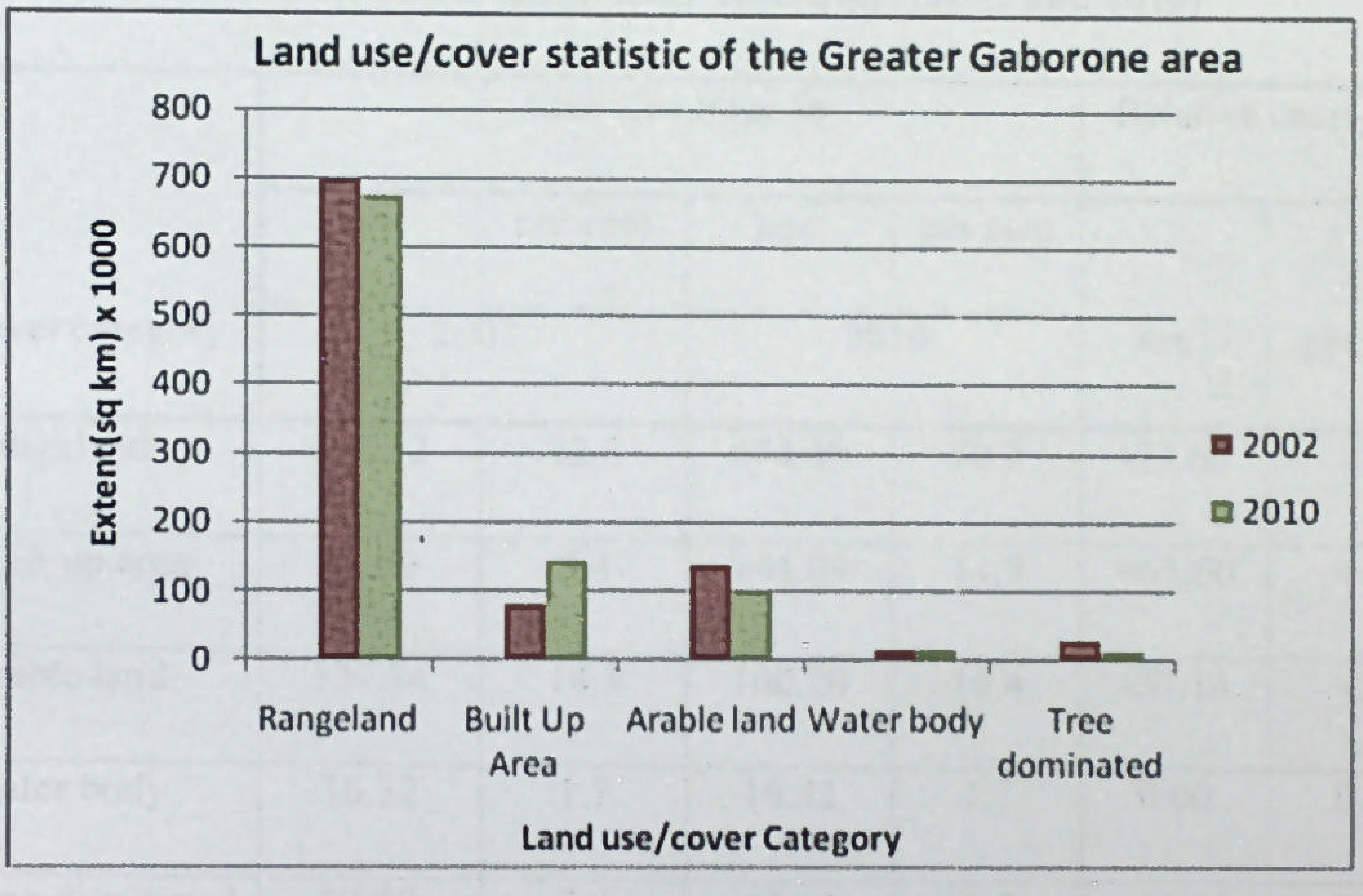

Figure 4.1: Land cover statistic for the Greater Gaborone (2002 and 2010)

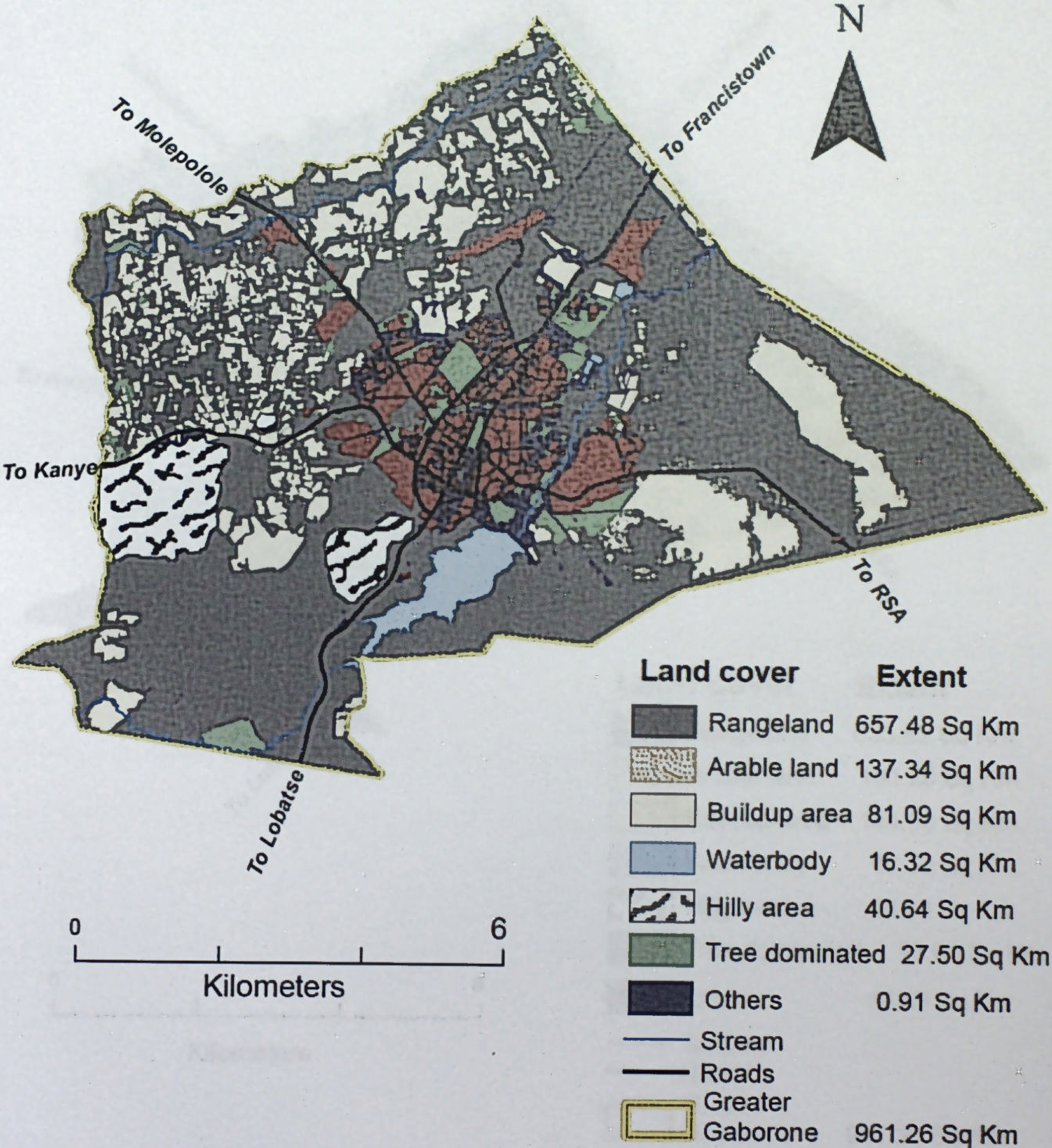

Figure 4.2: Land cover map of the greater Gaborone, 2002

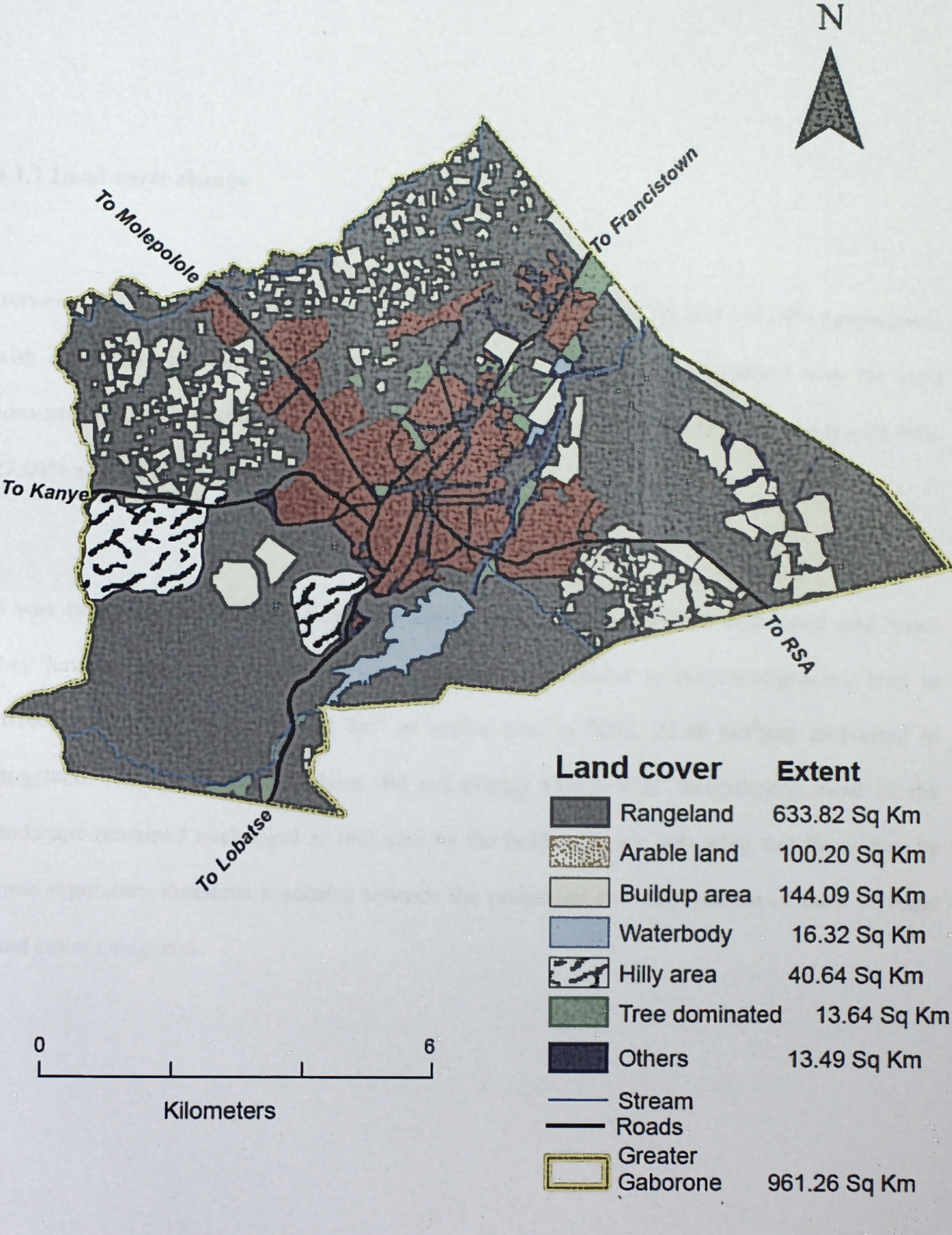

Figure 4.3: Land cover map of the greater Gaborone, 2010

4.1.1 Land cover change

Between 2002 and 2010, build up area and others increased by 77.7% and 1382.4% respectively with quantities of 63 km^2 and 12.58 km^2 respectively. Extent wise, rangeland was the most converted while percentage wise, forest cover, arable land and rangeland decreased by 50.40%, 27.04% and 3.39% respectively in the same period.

It was evident during analysis that some arable fields in 2002 had been abandoned and hence they have undergone a change in cover characteristic similar to rangeland/grazing land in 2010.Consequently of the 137.34 km^2 of arable land in 2002, 21.46 $km^2$was converted to rangeland in 2010.Water body/dams did not change (Table 4.2). Nevertheless most of the landscape remained unchanged as indicated by the bolded figures indicating that there may be some regulatory measures mandated towards the protection and management of each of these land cover categories.

Table 4.2: Land cover change matrix

Land use/cover type in 2010	Land use/cover type in 2002							Changes in 2010	
	RL	BU	AL	WB	TD	OT	Total	Change(SqKm)	Change (%)
RL	**652.17**	0.00	21.46	0.00	0.82	0.01	674.46	-23.66	-3.39
BU	44.08	**81.09**	9.00	0.00	9.30	0.62	144.09	63.00	77.69
AL	1.28	0.00	**98.85**	0.00	0.01	0.00	100.20	-37.14	-27.04
WB	0.00	0.00	0.00	**16.32**	0.00	0.00	16.32	0.00	0.00
TD	0.03	0.00	0.00	0.00	**13.61**	0.00	13.64	-13.86	-50.40
OT	0.56	0.00	8.03	0.00	3.74	**0.27**	13.49	12.58	1382.42
Total	698.12	81.09	137.34	16.32	27.50	0.91	961.26		

Note: RL = rangeland, BU = built up area, AL = arable land, WB = water body/dams, FR = forest cover and OT = others; the area of each land use/cover category that remained the same was marked in bold

4.1.2 Urban expansion in the greater Gaborone

Urban area maps (Figures 4.4 and 4.5) depicts the built up environment between 2002 and 2010 and its extent. Change in buildup area between the two study years is illustrated by Figure 4.6. The buildup area measured 81.09 km^2 and 144.09 km^2 respectively between the same period (Table 4.2) while population in 2001 was 257 930 and 364 332 in 2011 (Table 4.6).

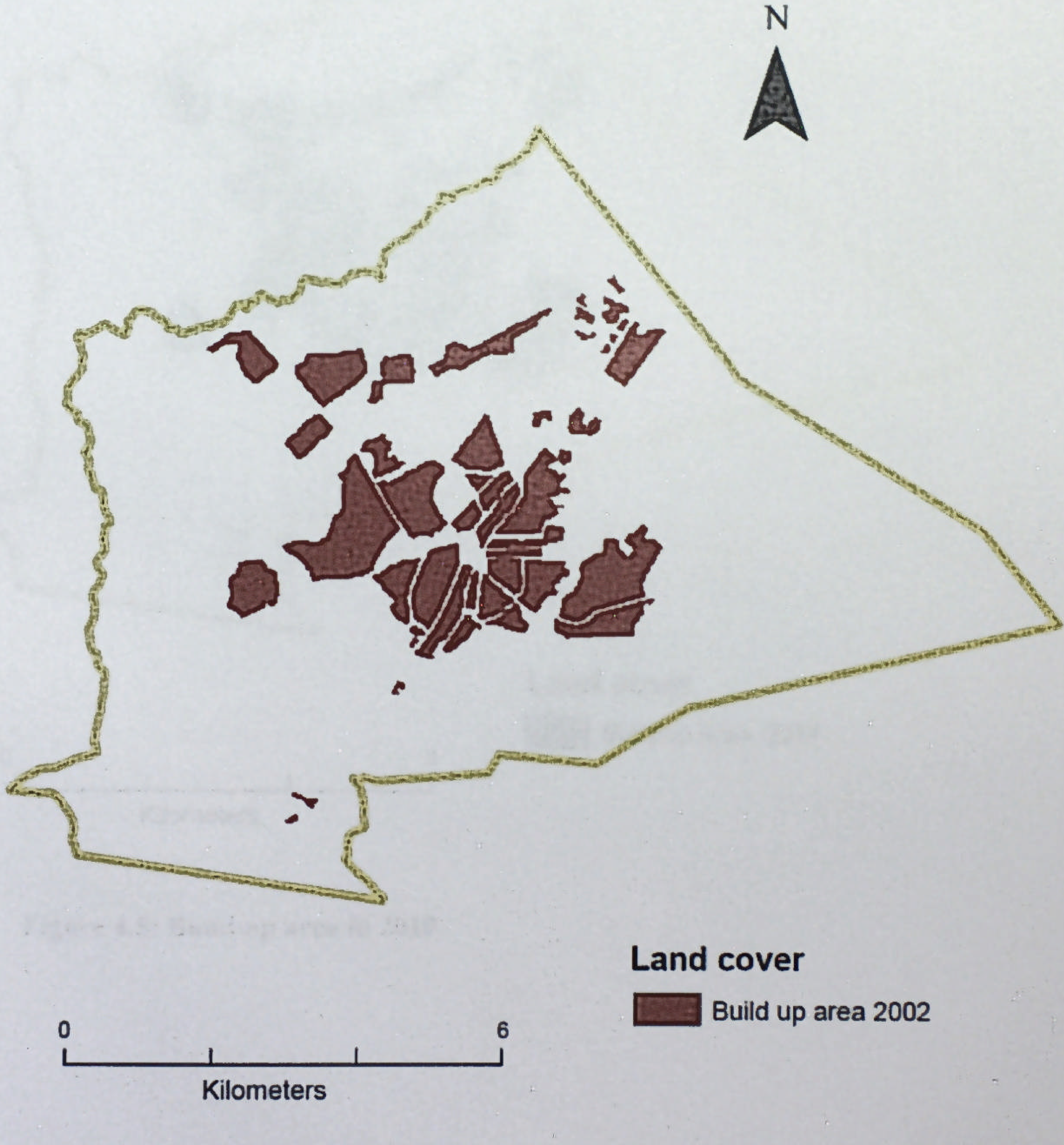

Figure 4.4: Build up area in 2002

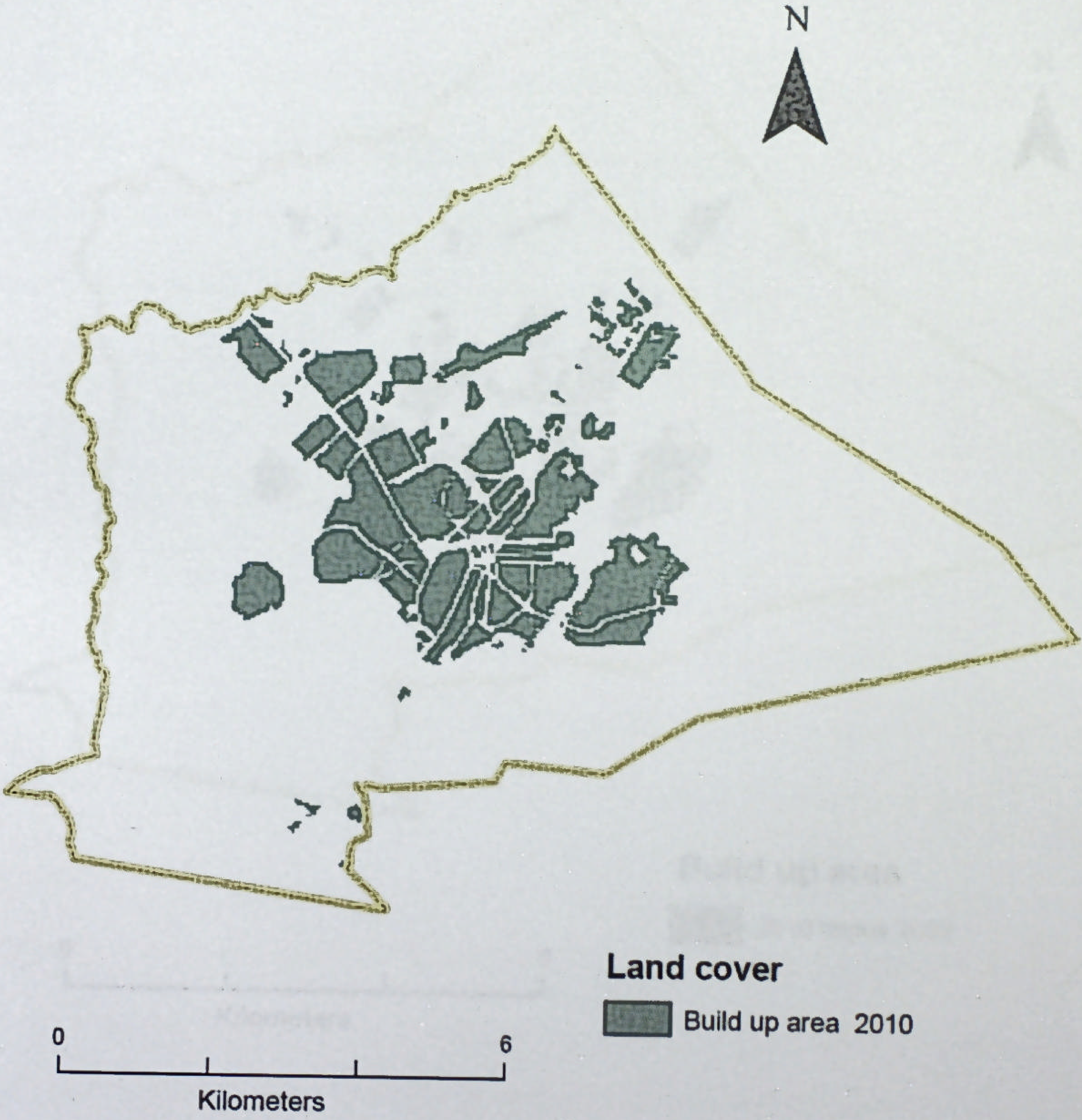

Figure 4.5: Build up area in 2010

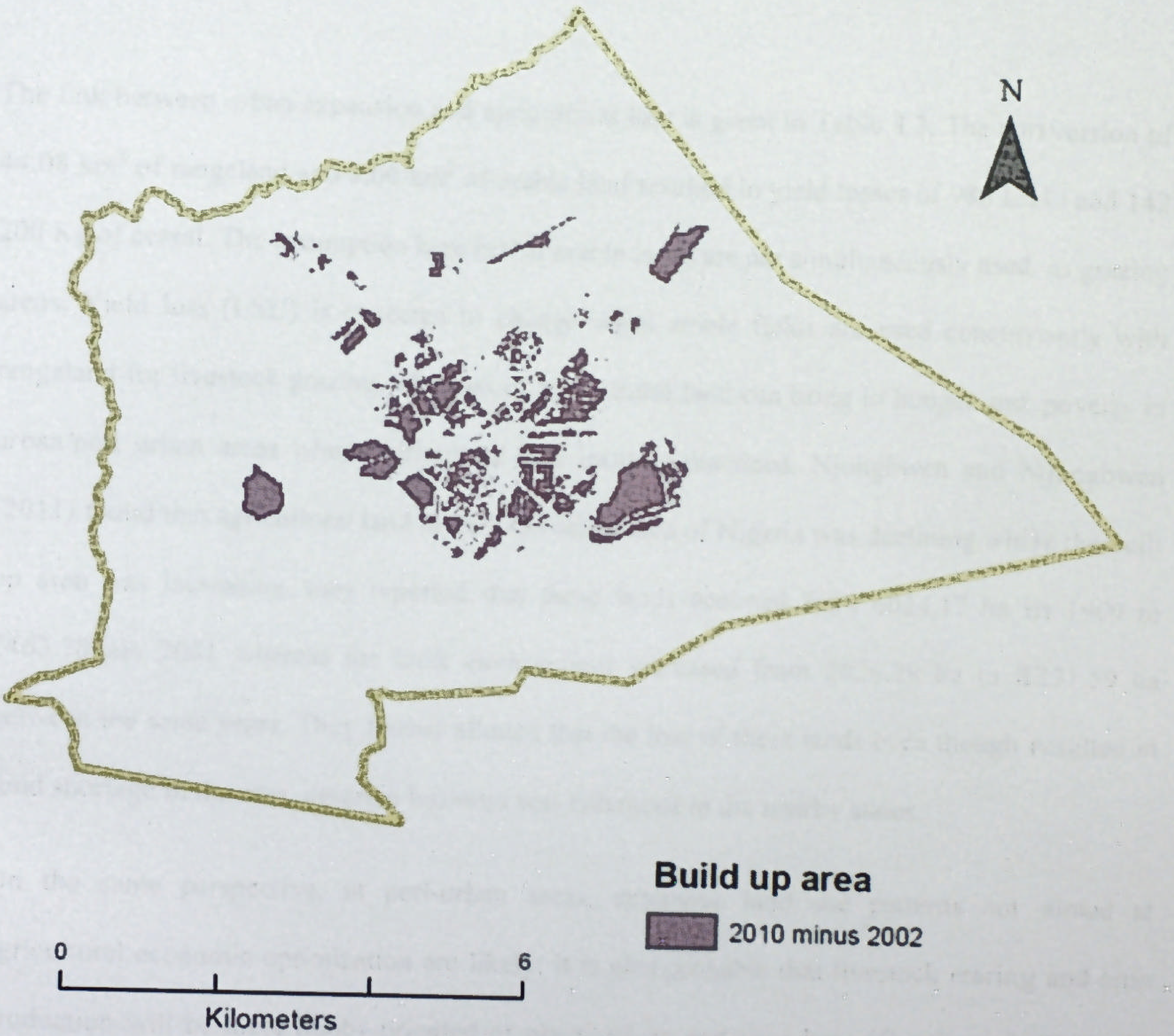

Figure 4.6: Build up area change map

4.1.3 Effects of urban expansion on agricultural production loss.

The link between urban expansion and agricultural loss is given in Table 4.3. The conversion of 44.08 km^2 of rangeland and 9.00 km^2 of arable land resulted in yield losses of 980 LS U and 142 200 Kg of cereal. The assumption here is that arable lands are not simultaneously used as grazing areas. Yield loss (LSU) is expected to change when arable fields are used concurrently with rangeland for livestock grazing. The loss of agricultural land can bring in hunger and poverty in urban/peri urban areas where agriculture was initially practiced. Njungbwen and Njungbwen (2011) found that agricultural land in the Uyo urban area of Nigeria was declining while the built up area was increasing, they reported that these lands declined from 6024.17 ha in 1969 to 2463.78hain 2001 whereas the built environment increased from 2626.29 ha to 8231.59 ha between the same years. They further alluded that the loss of these lands even though resulted in food shortage in the area, agrarian business was enhanced in the nearby states.

On the same perspective, in peri-urban areas, extensive land use patterns not aimed at agricultural economic optimization are likely; it is also probable that livestock rearing and crop production will be more hobby-oriented or practiced on part time bases(Busck et al, 2006).On the same context, further conversion of rangelands and arable fields to build up area is likely to reduce their capacity to support livestock and arable farming and consequently denting the potential of subsistence farmers attaining a self sufficiency status.

Table 4.3: Agricultural production loss

Land converted to build up area (hectares)		Yield forfeited	
Rangeland	4 408	LSU forfeited	980
Arable land	900	Kg of cereal forfeited	142 200

The conversion of agricultural lands has impacts on agricultural production, the resultant mostly being the loss in production. Consequent to rangeland and arable land conversion to build up area, 980 cattle and 2 844 50 Kg bags were forfeited thus agricultural production loss (Table 4.4). In a study done in the vine yards of Frascati, Italy, the cultivable area of vine yards have been found to have decreased from 1082.48 ha to 1021.99 ha between 2005 and 2008 linking this loss to urban developments (Loret and Ioannilli, 2011). This trend has resulted in low wine production. Even though these findings are not linked to rangeland and arable land, the notion is that the loss of agricultural land to build environment is likely to depress production.

Table 4.3a: Agricultural production loss

Yield loss	Pula
980 cattle	101 738 70
2 844 50Kg bags	337 014

4.2 Relating land cover transitions to population

Urban and peri urban areas are characterized by the concentration of people, and hastened urban growth is usually linked with and driven by the population concentration in an area (Long et al, 2008).This trend is likely to continue over the years as most of the amenities particularly higher learning institutions and large shopping malls are found in the study area. Therefore these facilities lure people to settle in their vicinity in pursuit for education, employment and the perceived better lifestyle (Wu et al, 2008). The projected population for the study area in 2035 is 699 409 (Table 4.5), this increase in population necessitates for the provision of land for housing as well as infrastructural development thus adding more pressure on land resources.

On the same context, rangeland and arable land showed a decrease of 3.39 % and 27.04% respectively between 2002 and 2010. (Table 4.2). The conversion of rangeland and arable land to build up area may signal their vulnerability to be converted to that category consequent to the resource needs (urban infrastructure) of the growing population (Table 4.5). In areas where there is an increasing population especially in urban and peri urban areas, rangelands or agricultural land in general have been found to be abandoned and later on converted to urban uses (Njungbwen and Njungbwen, 2011). Such a development is likely to negatively impact subsistence farmers efforts towards food self sufficiency, that is while at the fringes farmers wish to increase their herds, the grazing areas are lessening, a practice which is likely to discourage potential subsistence farmers.

Table 4.5: Population of the greater Gaborone area (2001, 2011 and 2035)

Name of locality	Years		
	2001	2011	2035
Gaborone	186 007	233 135	351 451
Mogoditshane	32 843	57 637	141 064
Tlokweng	21 113	35 982	85 187
Gabane	10 399	14 842	28 272
Metsimotlhabe	4 056	8 081	22 505
Mmopane	3 512	14 655	70 930
Total	257 930	364 332	699 409

Predictably, the population for the study area in the year 2035 will be 699 409and its potential built up/urban area extent is 282.54 km^2 (Table 4.6 and Figure 4.7). Population growth in the study area means that land resources in the study area will be under pressure of satisfactorily meeting its demand. Population growth and sprawl in the study area are likely to intensify the competition for land among rangeland, arable land and the built up area (Batisani and Yamal, 2010). The continued increase in population and expansion of the build up area is likely to reduce the agricultural land subsequently forfeiting yield. Thus impacting communal subsistence farmers' agricultural production.

Table 4.6: Relating population size and built up area expansion

Parameter	Years		
	2001	2011	2035
Population size	186 007	356 681	699 409
Build up area (Km^2)	81.09	144.09	282.54

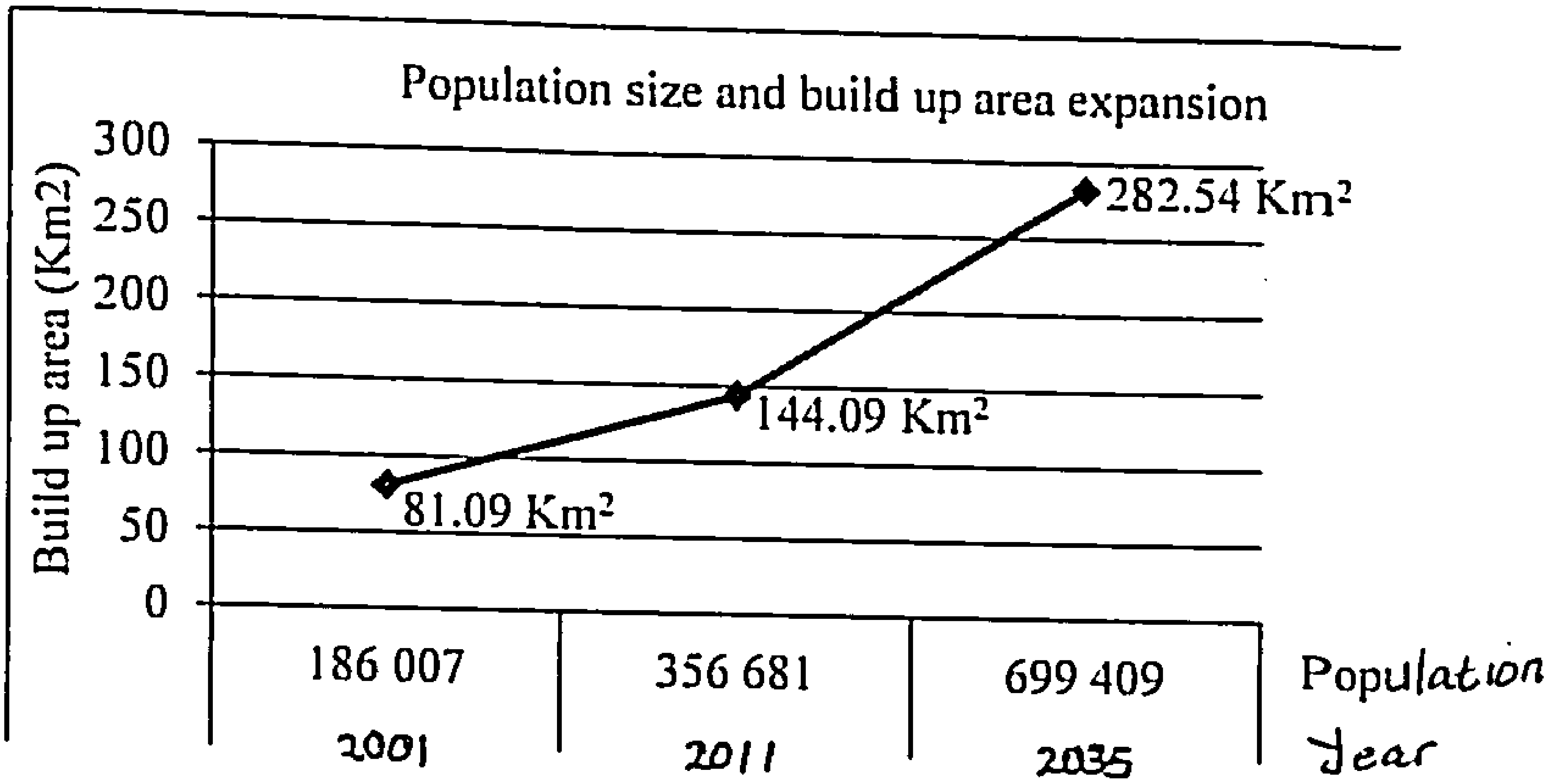

Figure 4.7: Relationship between population size and potential build up area

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The goal of this study was to explore the dynamics of urban landscapes in response to urbanization in the greater Gaborone area between 2002 and 2010. The results of this study revealed that the greater Gaborone area was covering an area of 961.26 km^2 in 2002 and the same extent in 2010. Proportionate to the extent of the study area; rangeland was the dominant land cover (72.6% in 2002 and 70.2% in 2010). Arable land was covering 14.3% and 10.4% while build up area was covering 8.4% and 14.9%, in 2002 and 2010, respectively.

Results of the analysis also show that land cover classes have undergone a change with differing magnitudes. The transition matrix highlights that amid these changes, 44.08 km^2 of rangeland and 9.00 Km^2 of arable land were converted to build up area from 2002 to 2010, signifying the pressure posed by urban expansion on these agricultural lands. Production wise, these conversions resulted in forfeiture of 980 LSU and 142 200 Kg of cereal worth 101 738 70 and 337 014 pula, respectively.

Population has been found to be increasing in the study area from 2001 when it was 257 950 to 364 322 in 2011. Within the same period also, rangeland and arable land decreased by 23.66 km^2 and 37.14 km^2 respectively while the built environment increased by 63 km^2.By the year 2035 the predicted population for the area will be at 699 409 necessitating a 282.54 km^2 of built environment undoubtedly from agricultural land (rangeland and arable land), if conditions in the study area stay the same.

Even though urban expansion and land cover changes are linked to the physical conditions of a locality, other prevailing conditions are also influential in shaping the urban landscape. The socio economic factors, land policies or regulations and the individual behavior of the land users also contribute to urban expansion. The greater Gaborone thus encompasses the Gaborone city which is central to socio economic activities, policies and a concentrated population. These factors can highly influence the cover changes in these areas. It is therefore important to integrate methods of research like GIS and RS together with social surveys which will provide dependable data to study the urban environments with the aim of providing bases for planning towards sustainable urban development.

5.2 Recommendations

1. Urban expansion has become an environmental concern the world over and its impact is rapidly surfacing. To abate the impacts of this occurrence, ways of urban development that promote sustainability could be incorporated in the civic land use plans, for example the introduction of a smart growth policy (EPA, 2001) where emphasis is on vertical development as opposed to lateral. Through this guiding principle coupled with sound resource management practices, agricultural lands can be preserved and agronomic activities in this area could be revived ultimately improving yields and self - sufficiency.

2. Expansion of the built environment is correlated to population growth therefore measures to control the concentration of population in urban areas could be devised. These strategies could include decentralizing the provision of facilities, services, infrastructural development and resources in areas neighboring the greater Gaborone city and beyond. This practice could minimize population concentration in the study area because people are likely to dwell in the vicinity of areas they deem convenient in terms of facilities, services and their resource needs.

3. Public involvement in decision making should be commended as it could enhance the assessment of the likely impacts of urban expansion on the surrounding environments.

Land institutions should also work together irrespective of their administrative level for sustainable development and apt ecological management.

4. Further research is required to tackle the policy dimensions of LUCC in the study area as well as the use of time series imagery analysis to help predict the probable urban expansion pattern and the possible impacts, for the years to come.

REFERENCES

Adedeji, H. and Ademiluyi, I. A. (2009).Urban agriculture and urban land use planning for a synthesis in metropolitan Lagos, Nigeria. *Journal of geography and regional planning* volume 2, No.3. pp. 0430-0500.

Adell, G. (1999) Literature review theories and models of the peri-urban interface: A changing conceptual landscape, *Peri-urban research project team, development planning unit*, University College London.

Adell, G. (2001).Theories and models of the Peri urban interface.A changing conceptual landscape. Strategic environmental planning and management for the *peri-urban interface research project. Development planning unit*. University College London.

Agarwal, C., Green, G. M., Grove, J. M., Evans, T. P., and Schweik, C. M. (2002). A review and assessment of land-use change models: Dynamics of space, time, and human choice. *General technical report NE-297*. Newtown Square, Pennsylvania: U.S. department of agriculture, forest service, Northeastern research Station. 61 pp.

Ahmad, Z., Ahmad, N and Abdullah, H. (2009).Urbanism, space and human psychology: Value change and urbanization in Malaysia. *European journal of social sciences*.Volume 11, No. 3.

Akiyode, O. O. (2010).Environmental security in developing economy megacity: A case study of Lagos,Nigeria. *Journal of sustainable development in Africa.*Volume 12 No. 5. pp. 294 – 301.

Allen, A., Nilvo L. A., da Silva and Enrico Corubolo.E.(1999).Environmental Problems and opportunities of the Peri-urban interface and their impact upon the poor. Draft for discussion, *Peri-urban research project team. Development planning unit*, University College London.

Allen, A. (2003).'Environmental planning and management of the Peri urban interface'.*Environment& Urbanization*, Volume 15, (No.1) pp. 135-147.

Allen, A., Davila. J. D., and Hofmann, P. (2006). The Peri-urban Water Poor: Citizens or Consumers?' *Environment and urbanization*.IIED.pp 333 – 350.

Anderson, J.R., Hardy, E.E., Roach, J.T. and Witmer.R.E. (2001). A land use and land cover classification system for use with remote sensing data. *A revision of the land use classification system as presented in U.S. Geological Survey Circular 671*. United states government printing office, Washington.USA.

Araya, Y.H. (2009).Urban land use change analysis and modeling: A case study of Setubal and Sesimbra, Portugal. *Master thesis*.Institute for geoinformatics.University of Munster.Berlin, Germany.

Atasoy, M.; Karslı, F.; Bıyık, C.; Demir, O. (2006) Determining Land Use Changes with DigitalPhotogrammetric Techniques. *Environmental Engineering Science* 2006, *23* (4), 712-721

Batisani, N. and Brent, Y. (2010).Elasticity of capital land substitution in housing construction, Gaborone Botswana: Implications for smart growth policy and affordable housing. Landscape and urban planning.*An international journal of landscape ecology, planning and design*.pp 77 – 81.

Briassoulis, H. (1999). Analysis of land use change: *Theoretical and modeling approaches*, Morgantow, PA.

Busck G.A., Pilgaard K.S., Praestholm S., Reenberg A. and Primdahl .J. (2006).Land system changes in the context of urbanization - examples from the peri-urban area of greater Copenhagen. *GeografikTidsskrift/Danish Journal of.Geography*. (106):pp 21-34.

Berberoglu .S and Akin.A,(2009). Assessing different remote sensing techniques to detect land use/cover changes inthe eastern Mediterranean International Journal of Applied Earth Observation and Geoinformation

Center for Applied Research CAR, (2005). Crop-livestock systems development in southern Africa: priorities for future research. Botswana country repor.pp.1-47.

Codjoe, S.N.A. (2007). Integrating remote sensing, GIS, census, and socioeconomic data in studying the population land use/cover nexus in Ghana: A literature update. *African Development*, 32(2), 197-212

Coppin. P, Jonckheere.I,.Nackaerts. K, Muys.B, Lambin.E: (2004) Digital change detection methods inecosystem monitoring: Int. J. Remote Sens.25, 1565–1596

CSO.(2001).Population of towns, villages and associated localities. *Department of printing and publishing services.* Gaborone, Botswana.

CSO. (2003) Annual Agricultural Survey Report, *MoA*. Gaborone, Botswana

CSO.(2006). Annual agricultural survey report.*MoA*. Gaborone, Botswana.

d'Allonnes, T.R. (2006). Economic impact of BMC price increases. Southern Africa global competitiveness hub.*Regional center for Southern Africa, U.S. Agency for international development.* Gaborone, Botswana.

EPA .(2001). What is Smart Growth? United States *Environmental Protection Agency* [online] http://epa.gov [Accessed August 2012]

FAO. (1996).The state of food and agriculture .*Food security: Some macroeconomic dimensions 1.*

FAO.(2007).Profitability and sustainability of urban and peri-urban agriculture.*Agricultural management, marketing and finance occasional paper No. 19.* Rome, Italy.

FAO.(2011).Food, agriculture and cities.Challenges of food and nutrition security, agriculture and ecosystem management in an urbanizing world.*Food for the Cities multi-disciplinary initiative position paper.* Rome, Italy. pp.6- 44.

Fazal, S. (2000).Urban expansion and loss of agricultural land – a GIS based study of Saharanpur City, India.*Environment and urbanization volume* 12 No.2.Aligarh Muslim university. Aligarh.India.pp. 133- 149.

GECAFS.(2005).Science plan and implementation strategy.*Earth system science partnership.* Wellington, report No.2 pp 36.

Government of Botswana,(1980).Town and Country Planning Act. Gaborone. The government printer

Gwebu, T. (2004) Patterns and trends of urbanization in Botswana and policy implications for sustainability. Gaborone.

ITC, (2005). Education 2005-2006. *International Institute for Geo-Information Science and earth Observation,* University of Twente.Enschede, The Netherlands.28pp

Jat, M. K.; Garg, P.K.; Khare, D. (2008) Monitoring and modeling of urban sprawl using remote sensing and GIS techniques. *International Journal of Applied Earth Observation and Geoinformation.*10(1), 26–43.

Lambin, F.E., Helmut, J.G. and Lepers, E. (2003). Dynamics of land use and cover changes in tropical regions. *Annual review of environmental resources.*LUCC international project office. . University of Louvain. Louvain-la-Neuve.Belgium

Lambin, F.E. and Meyfroidt, P. (2011). Global land use change, economic globalization, and the looming land scarcity. *Series of inaugural articles by members of the national academy of sciences.*

Leemans, R., Lambin, E.F., McCalla, A., Nelson, J., Pingali, P. and Watson B. (2003). Drivers of change in ecosystems and their services. In ecosystems and human well-being: A Framework for assessment, Editors. Mooney, H. and Cropper, A. WReid, Washington DC:

Long, H.L.; Wu, X.Q.; Wang.W.J.and Dong, G.H. (2008). Analysis of urban-rural land-use change during 1995-2006 and its policy dimensional driving forces in Chongqing, China. *Sensors* 8, 681-699.

Loret, E. and Ioannilli, M. (2011). Spatial analysis of the increasing urbanization trend in the Frascati wine designation of origin (DOC) area: A geostatistical approach. *Journal of geography and regional planning* Volume.5 No.13. pp. 346-352.

Lu.D, Mausel. P, Brondízios. E , Moran. E. (2004): Change detection techniques, Int. J. Remote Sens. 25, 2365–2407

Makhamreh, Z. and Almanasyeh, N. (2011).Analyzing the state and pattern of urban growth and city planning in Amman using satellite images and GIS.*European journal of social sciences.* Volume 24, No. 2. pp. 252 – 262

Mandere, M., Ness. B. and Anderberg ,S. (2010).Peri-urban development, livelihood change and household income: A case study of peri-urban Nyahururu, Kenya. *Journal of agricultural extension and rural development* Vol. 2 (5) pp. 73-83, June, 2010

Marshall, F., Waldman, L., MacGregor, H., Mehta, L. and Randhawa, P. (2009)On the edge of sustainability: Perspectives on Peri-urban dynamics, STEPS Working Paper 35, Brighton: STEPS Centre. pp. 1- 53.

Mas J.F. (1999): Monitoring land-cover changes: A comparison of change detection techniques, Int. J. Remote Sens. 20, 139–152

Mathuba, B.M., (2003).Paper presented at an International Workshop on Land Policies in Southern Africa. Berlin, Germany.Ministry of Lands and Housing.Gaborone, Botswana.

Meyer, W.B. and Turner, B.L. (1996). "Land-use/land-cover change: Challenges for geographers." *Geojournal*Volume 39(No.3): 237-240.

Ministry of Lands and Housing, (2002).Botswana National Land Policy Issues Report, Gaborone, Botswana. pp 1-103.

MoA.(2001).BRIMP. Gaborone, Botswana.

Mosha, A.C. and Cavric, B.I. (2001).Incorporating urban agriculture in Gaborone city planning.A case study of Glen Valley.Urban and regional planning unit.Department of environmental science.University of Botswana.Gaborone, Botswana. pp. 25 – 27.

Njungbwen, A. and Njungbwen, E. (2011). Expansion and loss of agricultural land in Uyo urban area: Implications for agricultural business. *Ethiopian journal of environmental studies and management.*Volume 4 No.4. pp. 74 – 82.

Nkambwe, M and Totolo.O. (2006).Customary land tenure saves the best arable agriculture land in the peri-urban zones of an African city: Gaborone, Botswana. *Applied geography* volume 25,pp. 26-46.

Ojima, D.S., Galvin, K.A., Turner, B.L II. (1994). The global impact of land-use change. *BioScience*44(5) pp,300–4

Oladele, B.M. and Oladimeji, B.H. (2011).Dynamics of urban land use changes with remote sensing: Case of Ibadan, Nigeria. *Journal of geography and regional planning.*Volume 4, No. 11.pp632–643.

Pickett, S.T.A., Cadenasso, M.L., Grove, J.M, Nilon, C.H., Pouyat, R.V., Zipperer, W.C and Costanza, R. (2001). Urban ecological systems: Linking terrestrial ecological, physical, and socioeconomic components of metropolitan areas. *Annu. Rev. Ecol. Syst.* 32:127-57.

Pontius.R.G and Safaa Z.A (2011).Size, intensity, and stationarityof land changesby interval, category, andtransition.Working Paper No. 2011-21. pp 1-30.

Quentin F. B., Jim, C., Julia, C., Carole, H., and Andrew, S.(2006). Drivers of land use change, final report: Matching opportunities to motivations, *ESAI project 05116*, Department of sustainability and environment and primary industries, Royal Melbourne Institute of technology. Australia.

Reis, S. (2008). Analyzing land use/land cover changes using remote sensing and GIS in Rize, North-East Turkey. *Sensors* 8, 6188 – 6202.

Renner, M. (1998). Environmental and social stress factors, governance, and small arms availability. The potential for conflict in urban areas.Project on urbanization, population, environment, and security.*Comparative urban studies project occasional paper* No. 15.Supported by the U.S. Agency for International Development through a cooperative agreement.Woodrow Wilson international center for scholars.

Republic of Botswana. (1992). Land Problems in Mogoditshane and other Peri-Urban Villages: Government Paper No. 1 of 1992.Gaborone. The Government Printer.

Rogana J.; Chen, D. (2004).Remote sensing technology for mapping and monitoring land-cover and landusechange.*Progress in Planning* 2004, *61*, 301–325

Rimal, B. (2011). Application of remote sensing and GIS, land use/land cover change in Kathmandu metropolitan city, Nepal. Ph.D. student.Faculty of earth science and environmental management institute of geography, University of Wroclaw.*Journal of theoretical and applied information technology*. pp. 80 – 85.

Sanli, F.B (2011).Monitoring land use/cover change and its effects in a highly urbanized district of a metropolitan city Istanbul, Turkey.*International journal of the physical sciences* Volume. 6 No.12, pp. 2907-2915.

Simon, D., McGregor, D., and Thompson, D. (2006). Contemporary perspectives on the peri-urban zones of cities in development areas, Inperi-urban interface: Approaches to sustainable natural and human resource use, edited by D. McGregor, D. Simon, and D. Thompson, pp. 3-17. London, UK: *Earthscan Publications* Ltd

Soffianian, A., Nadoushan, A., Yaghmaei, L and Falahatkar, S. (2010). Mapping and analyzing urban expansion using remotely sensed imagery in Isfahan, Iran. *World applied sciences journal.*Volume 9, No. 12).pp 1370-1378.

Tufts University. (2007). Arc GIS tip sheet. How to align a non-georeferenced image to an existing geographic layer or georeferenced image.Turfs university.

Ujoh, F., Kwabe, I.D. and Infatimehin, O.O. (2010).Understanding urban sprawl in the federal capital city, Abuja: Towards sustainable urbanization in Nigeria. *Journal of geography and regional planning* volume 3, No.5.pp.106-113.

UNEP.(2009).Bioenergy issue paper series, Paper No.1.Land use, land use change and bioenergy.

Weng, Q. (2002) Land use change analysis in the Zhujiang Delta of China using satellite remote sensing, GIS and stochastic modeling *Journal of Environmental Management*64, 273–284.

Wu, J. and Irwin, E. (2003).Human-nature interactions and the spatial pattern of land use. Presented at the 2003 AERE workshop "*spatial theory, modeling, and econometrics in environmental and resource economics*" Madison, Wisconsin.

Wu, X., Shen, Z., Liu, R. and Ding, X. (2008).Land use/cover dynamics in response to changes in environmental and socio-political forces in the upper reaches of the Yangtze River, China. *Sensors* 8, 6188-6202.

APPENDICES

Appendix 1: BMC price structure by grade

PRICE STRUCTURE BY GRADE

LOBATSE AND FRANCISTOWN ABATTOIR

EU Compliant Cattle

CATTLE Week 23 4-Jun-2012 to 10-Jun-2012

		<179.99	>=180<199.99	>=200<219.9	>=220<239.99	>=240<259.99	>=260<269.99	>270
PRIME		11.00	22.62	22.77	23.57	23.27	23.07	23.07
SUPER		11.00	19.37	19.57	20.07	19.97	19.82	19.82
GRADE 1		11.00	18.44	18.69	19.09	18.99	18.89	18.89
GRADE 2		11.00	17.60	17.90	18.30	18.20	18.10	18.10
GRADE 3	S3	8.50						
GRADE 4	S4	7.00						
CANNING	SM	4.50						
CONDEMNED		150.00 per head						

Non-EU and Detained Cattle

	Weight range	<179.99	>=180<199.99	>=200<219.9	>=220<239.99	>=240<259.99	>=260<269.99	>270
PRIME		11.00	22.62	22.77	22.77	22.77	22.52	22.52
SUPER		11.00	19.57	19.57	19.57	19.57	19.32	19.32
GRADE 1		11.00	18.44	18.69	18.69	18.69	18.44	18.44
GRADE 2		11.00	17.60	17.90	17.90	17.90	17.65	17.65

Prices for Grade3, Grade 4, Canning and Condemned are the same as for EU compliant Cattle

NB: These prices are in PULA per kilogram

Farmers are reminded that the Department of Animal Health and Production is willing to assist those that wish to load cattle to BMC on Sundays. However, farmers should make the necessary appointment with the Extension Office in their area.

Appendix 2: BAMB producer prices

Botswana Agricultural Marketing Board

Reference:
Date:

2012/2013 MARKETING SEASON

PRODUCER PRICES FOR SCHEDULED PRODUCE

Botswana Agricultural Marketing Board has set producer prices as shown below. These prices are for delivery at all our branches across the country: Pitsane, Kanye, Moshupa, Gaborone, Mahalapye, Palapye, Serowe, Selibe Phikwe, Francistown, Maun and Pandamatenga.

		Bag	Tonne
SORGHUM	Grade 1	130.00	2,600.00
	Grade 2	91.00	1,820.00
BITTER SORGHUM	Grade 1	91.00	1,820.00
	Grade 2	63.70	1,274.00
MILLET	Grade 1	130.00	2,600.00
	Grade 2	91.00	1,820.00
WHITE MAIZE	Grade 1	118.50	2,370.00
	Grade 2	82.95	1,659.00
YELLOW MAIZE	Grade 1	118.50	2,370.00
	Grade 2	82.95	1,659.00
SUNFLOWER	Grade 1	121.91	4,023.00
GROUNDNUTS	Grade 1	440.00	8,800.00
	Grade 2	308.00	6,160.00
TSWANA COWPEAS	Grade 1	400.00	8,000.00
	Grade 2	280.00	5,600.00
BLACK-EYE COWPEAS	Grade 1	400.00	8,000.00
	Grade 2	280.00	5,600.00
WHITE HARRICOTS	Grade 1	320.00	6,400.00
	Grade 2	224.00	4,480.00
JUGO BEANS	Grade 1	420.00	8,400.00
	Grade 2	294.00	5,880.00
TEPARY BEANS	Grade 1	320.00	6,400.00
	Grade 2	224.00	4,480.00
CHINA PEAS	Grade 1	360.00	7,200.00
	Grade 2	252.00	5,040.00

NB
The above prices have been set in line with the market, and are valid until **31st August 2012.** They will be adjusted to stay in line with the market prices whenever major changes occur. Prices of all crops except sunflower seed are for 50 kg bags. Sunflower seeds prices are for 30 kg bags. The price excludes the cost of bags. Producers who deliver in new plastic bags will be paid an allowance of P2.00 per bag.

M. Mphathi
Chief Executive Officer

Plot 130, Unit 3&4 Gaborone International Finance Park, Nkwe Square • Private Bag 0053 Gaborone, Botswana
Phone (+267) 395-1341 • Fax [illegible] • www.bamb.co.bw

Appendix 3: Extent of land use/cover of the greater Gaborone in 2002

Category	Count	Minimum	Maximum	Sum (Sq meters)	mean	stdv
Buildup	611	233.797852	6696863.27	81088106.77	133529.9626	505123.6162
Arable	831	1081.894503	4944785.641	137852363.3	166487.4413	350480.3804
Rangeland	88	16516.28495	112491191.3	698937287.9	7948136.23	16104900.41
Tree dominated	93	5353.951792	3266798.113	28052337.14	307000.4037	525434.4235
Greater Gaborone	1	961260036.7	961260036.7	961260036.7	961260036.7	0
Waterbody	5	48543.63481	15865378.67	16323795.97	3364499.274	6252324.421
Others				906013.21		

Appendix 4: Extent of land use/cover of the greater Gaborone in 2010

Category	Count	Minimum	Maximum	Sum (Sq meters)	mean	stdv
Buildup	108	10003.07979	11628632.3	144087943.3	1334147.623	2111979.615
Arable	272	16369.28664	4426122.787	100203146.4	368393.9205	638770.9855
Rangeland	49	115121.1029	164180568.5	674460506.8	13764500.14	32877110.27
Tree dominated	24	100250.9387	2603683.962	13643909.96	568496.2484	534067.6847
Greater Gaborone	1	961260036.7	961260036.7	961260036.7	961260036.7	0
Waterbody	5	48543.63481	15865378.67	16822496.37	32664499.274	6252324.421
Others				13496042.65		