High-Resolution Mapping of Land Use Change and Urban Sprawl
By Means of Remote Sensing and GIS:
A Case Study of Goreangab Township, Windhoek

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Three A3 sized maps of Land Use (2001, 2011, and 2001-2011 comparison) in high resolution.

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Declaration

I, Lovisa Ruth Nangombe, hereby declare that this report is my own original work and not a reproduction of somebody else's work. Any information sourced from other people and institutions has been clearly indicated as such. This work has not been submitted for a degree at any other tertiary institution or published anywhere.

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(*Place, Date)* *(Signature)*

Executive Summary

This paper identifies and maps urban-fringe land use categories and their change over time in the township of Goreangab on the outskirts of Windhoek, Namibia. Urban fringe areas of many large cities are prone to urban sprawl and looming of informal settlements. The Goreangab Township is no exception in that, it too, is mostly made up by informal settlements. Also, typically, the township has experienced major transformations in the last two decades.

In order to determine the amount and type of Land Use (LU) and use change, high-resolution aerial photographs of 2001 and 2011 were used to map in detail a section of Goreangab. A study area of 1.374 km² (137.4 hectares) was selected to reflect one of the most dynamically changing areas of the township.

The pixel size of 0.5 m allowed for the identification of seven LU categories, namely Built-up Structures, Incomplete Structures, Big Trees, Small Outside Bathrooms, Net Shades, Transportation Networks, and Property Enclosures.

Some classes were only added to the map after analysis of the more recent data set, as Net Shades and Property Enclosures only developed in 2011, but were not present in 2001. All the original categories have changed considerably within that period of ten years.

The categories of built-up Structures and Trees exhibit the most dramatic changes. The number of Structures increased from 639 in 2001 to 4906 in 2011. Respectively, their total area increased from 2.4 hectares (2001) to 13.8 hectares (2011), representing an increase from 2% of the total study area in 2001 to 10% in 2011. Incomplete Structures are visible on both images of 2001 and 2011, indicating the rapid and still ongoing rate of change.

Respectively, the increase of built-up Structures corresponds with the decrease in the Tree category to clear land. The Tree category covered 52 hectares or 4% of the study area (2001), but only 13.5 hectares or 1% in 2011.

In the Transportation category, paved roads have persisted, but many footpaths/ tracks on the original images have fully developed into unpaved roads which can now be used by vehicles. New tracks have also formed while some old ones have faded away or were replaced by other land use classes.

There were only few informal structures in 2001 so it was easy to manage their solid waste. This situation, however, changed dramatically until 2011. Even since 2011 up to date there has been a considerable increase in the number and sizes of visible dump sites in most parts of the area.

The high-resolution mapping allows for detailed environmental implications to be formulated, regarding increased risk of run-off, flooding, contamination and fire hazard.

The township continues to expand as the population grows, with numerous challenges for city planning and management as well as the environment. The mapped LU changes from 2001 to 2011 provide (i) a quantifiable representation of this process, (ii) a detailed indicator of predicted future changes, and (iii) a digital data base which can be used for present and future decision making.

1 Introduction

1.1 Background

Land Cover (LC) and Land Use (LU) changes on the periphery of cities are often a result of urban sprawl. ‘Land Cover’ refers to the description of space and the observed natural physical cover of the earth’s surface (Communities, 2001, p. 13). ‘Land Use’ on the other hand refers to the depiction of areas in relation to their socio-economic purposes or to the activities that humans carry out on land for different purposes by using land resources (Communities, 2001, p. 13). LC and LU are usually interlinked and they can be both inferred from each other. Furthermore, LU is more difficult to observe than LC since one cannot always gather satisfactory information by just observing and additional information may be required to draw conclusions (Communities, 2001, p. 13). A good example is the difficulty in deciding whether grasslands are used for agricultural purposes or not.

Updated information on LC and LU of an area is very important because it is required by national, regional, municipality and town planners to manage land developments and plan for change in an effective way. LU is a crucial consideration for the planning systems of many cities and towns all over the world (Harisson, 2006, p. 8). Areas where by marginal or very slow change occur; old land use maps may continue to provide adequate and useful information, but for areas where the landscape changes over a short period of time recent maps are required (Paul, Philipp, & Gong, 1992, p. 439).

Due to the increase in human population the way people utilise the land greatly influences the way many places on earth look (Haub, 2009, p. 2). Land clearing for infrastructural development is a major man-made change to the natural environment that leads to land cover change. People allocate various specific functions to the land. The land serves many purposes such as transport functions for roads and railways, settlement functions for offices and houses as well as industrial functions for shops and markets (Haub, 2009, p. 2). Various functions of land mostly eliminate each other since combining them is a challenge and they all require delineable space on land which is a limited resource (Haub, 2009, p. 2). Specific areas are selected for particular functions through the process of land use planning.

In Namibia, all major towns are experiencing rapid urbanisation which is reflected in the growth of informal settlements (Matthei & Mandimika, 2014, p. 2). Rural-urban migration, especially of young people in Namibia hoping for improved economic and social conditions, is one of the major factors that lead to urban sprawl (Matthei & Mandimika, 2014, p. 9). In regions like Erongo and Khomas 40% of the residents were born elsewhere, but moved to these regions. Hence the highest rates of migration are experienced there (Matthei & Mandimika, 2014, p.9).

The planning document produced by the City of Windhoek (no date), states that Windhoek has experienced unmeasured growth after Namibia attained independence in 1990 (City of Windhoek, n.d. p. 2). Rapid urbanisation in Windhoek leads to challenges like inadequate provision of land and housing to all the residents of the city. The local authorities are lagging behind in providing land for housing and other essential services; consequently, a high percentage of the urban population live in informal settlements (City of Windhoek, p. 4).

During the process of choosing a study area for this project a quick overview was carried out on how various cities and towns and in Namibia have grown and changed in terms of Land Use and urban sprawl over the years. Windhoek, Walvis Bay, Swakopmund, Henties Bay, Katima Mulilo and Rundu are some of the towns that have expanded over the years and are still expanding. Some parts of Windhoek are expanding rapidly, which is termed as urban sprawl. Urban sprawl in Windhoek occurs on the outskirts of the city and mainly in areas of the informal settlements. Goreangab informal settlement was selected to depict this process. Normal urban development in all suburbs of Windhoek is limited due to the fact that the city is surrounded by mountains. Some areas of Goreangab are very steep, therefore only few people choose to settle there and some patches remain vacant until today.

Mapping of the land use changes was done by means of Remote Sensing (RS) and GIS. RS refers to the process of gathering information about an object without being in physical contact with it. “GIS is the computerised database management system for the capture, storage, retrieval and analysis and display of the location of fully refereed data” (Ohri & Poonam, 2012, p. 13).

RS data can be used to classify LU and LC changes into various categories based on the spectral and spatial content of the data, the expertise of the interpreter, and the background knowledge of the study area.

1.2 Study aim and objectives

So far not much work has been done to map LC and LU change at a detailed scale for specific areas in Namibia. This study specifically focuses on the informal settlement section of Goreangab whereby urban sprawl is reflected and where significant changes have taken place from 2001 to 2011.

The study aims at producing detailed maps depicting Land Use changes that have taken place as a result of urban sprawl over the years at the informal settlement of Goreangab. The objectives of the study are to:

1. Identify various LC/ LU classes of the Goreangab informal settlement area
2. Identify zones where major changes have taken place
3. Attempt to forecast what might happen in the future in relation to population growth

2 Literature review

2.1 Urbanisation and urban sprawl

The urban area is a combination of natural and human made features; this makes it a complex system. Whenever urban development is taking place, land is always the most important and basic resource required (Gupta & Roy, 2012, p. 1014). Rapid growth rates of population is one of the characteristics that differentiates urban settlements from rural ones. Rural settlements are characterised by low population densities and loose networks of infrastructure, while urban settlements are made of spatially intensive industries (Adebayo, 2012, p. 1). Urban populations are usually with a large number of people that are crowded together in very small areas, compared to rural populations where people are spread widely across larger areas.

“World’s urbanisation currently stands at more than 50 % and it is likely to continue to rise to 75 % in many regions” (Matthei & Mandimika, 2014, p. 7). Currently, the majority of the world’s population live in urban areas. Observations on migration trends have indicated that by 2013 the ratio of the world’s population living in informal settlements will increase to 1 in 3 as compared to 1 in 6 in 2001 (Matthei & Mandimika, 2014, p. 7). Poverty has pushed one third of the world’s population to live in slums with no access to basic infrastructure and services (Matthei & Mandimika, 2014, p. 7).

According to the statistics of the United Nations, less developed countries’ growth rate is estimated at 97%, with Africa being the fastest growing continent (Sietchping, 2000, p. 555). While urbanization in developed countries is based on planning strategies, cities of less developed countries are characterised by rapid expansions that result in crises (Sietchping, 2000, p. 555). In Namibia, especially the capital city of Windhoek, the rate of urbanisation is very rapid. Informal settlers of Namibia stay in sub-standard structures because they are too poor to afford building proper houses, and the few that can afford to do so have no legal right to put up permanent structures (Matthei & Manidmika, 2014, p. 3). Inhabitants of these settlements lack adequate access to many services like water, sanitation, waste collection and proper roads.

According to Tiwari *et al.* (2012) urban sprawl can be defined as an “Awkward and irregular spatial growth of a town or a city mainly due to increase in population” (p. 22).The type of urban sprawl and the manner in which it occurs is greatly influenced by the increasing population of that particular area. Urban land use changes which are results of cities growth are mostly visible and common on the periphery of cities than in the city centres (Tiwari *et al.*, 2012, p.22).The increase of built up areas and changes related to urban land use patterns often lead to decrease in agricultural lands, vegetation cover as well as increased levels of water and air pollution (Tiwari *et al.*, 2012, p.22).

Urban sprawl can be classified by both qualitative and quantitative approaches. In the study of (Tiwari *et al,*. 2012, p.22) urban sprawl is classified qualitatively on the basis of growth geometry, built up land density, involvement of nature or man and spilled-out area in relation to administrative boundaries.

It is of great importance to study and understand the trends of urban sprawls, since they can be both, a potential for, and a danger to, growth and sustainable development. Utilising resources effectively in a way that ensures that infrastructures initiatives are allocated effectively is always a major concern for urban areas (Sararvanan & Ilangovan, 2010, p. 148). Depending on the city layout, e.g. in Cape Town, urban sprawl may also result in long travel distances due to fragmented and disperse activity patterns which make it difficult to have a practical public transport system in place (Future Cape Town, 2013, p. 4). One can only come up with a proper Land Use plan for an urban area if the urban sprawl of that area is identified and analysed (Saravanan & Ilangovan, 2010, p. 148).

Sietchping (2000) defines informal settlements as human establishments and Land Use types of the urban areas that are not suitable or adhering to the expected standards and regulations of that particular city or any other urban settlement. Informal settlements or slums as they are referred to in some parts of the world are mostly found in unsafe areas like deep valleys, flood prone areas, and health hazard areas in the proximity of waste dumps (Sietchping, 2000, p. 556). According to Aminipouri (2009), an informal settlement usually is identified by their physical and infrastructural environment, rather than by its residents' characteristics. It is therefore possible to identify such places from satellite and aerial imagery, since the identification is based on the characteristics of the place and not of its inhabitants (Aminipouri, 2009, p. 3). In addition to detecting and monitoring informal settlements; governments and planners also have to estimate the population of the informal settlements accurately. The use of RS data to estimate population has been practiced since 1970 (Aminipouri, 2009, p. 94).

While several studies have been conducted on the informal settlements of Namibia, none of them specifically deal with mapping land use changes. Begu (2003) focuses on the effective use of Geo-information for supporting feasibility studies of upgrading informal settlements. Nakanyete (2009) discusses the growth of informal settlements in Windhoek, various factors that force people to settle in informal settlements, and the challenges faced by the city of Windhoek to improve the living conditions in informal settlements. Similarly, Boltshauser & Stengel (2002) discuss environmental effects of urban-fringe land degradation in the vicinity of Goreangab Dam (northwestern Windhoek), but do not explicitly map Land Use in detail.

2.2 Land Cover (LC) and Land Use (LC)

The role of detailed Land Cover (LC) and Land Use (LU) mapping for fast-changing urban fringes is particularly crucial. Nowadays there is a high interest in LU and LC change caused by different human activities on the land. The ability to precisely describe and classify LC and LU is essential for defining sustainable land use systems that are appropriate for a particular place (Espach, 2006, p. 20). Detailed information on LU is required for monitoring environmental changes and it serves as land use statistics at different levels.

Identifying LU and LC classes facilitates the representation and analysis of units that enable us to establish a measurable link between human activities, environmental impacts, and their spatial dimensions (Communities, 2001, p. 15). LU/ LC information is also essential for integrating the temporal dimension in relation to the results of human activities. Land managers and policy makers can only monitor and predict changes if they have access to accurate, affordable and up-to-date Land Use maps (Finley, 2011, p. 7).

Identifying and analysing ongoing processes of a particular area to the extent that they can be mapped accurately is one of the major factors contributing to the value of LU/LC information.

The difference between LC and LU is that LC includes landscapes without human influence; some LC changes may occur from natural processes only. LUon the other hand is a result of humans influencing and changing existing LC for various purposes (Rimal, 2005, p. 80). Some landscapes are likely to change on a daily basis, particularly at a local scale as a result of human activity, e.g. building of new structures. When such minor changes accumulate, they alter landscapes at a regional or even national level (Finley, 2011, p.7).

Urban management also needs to understand the structure of a city for environmental purposes, e.g. storm water runoff control, urban forest planning, and air quality improvement. In order to better manage urban ecosystems and to improve environmental quality and human health in urban settlements, accurate maps of urban surface cover types are needed (Myeong *et al*., 2003, p. 243).

A lot of work on the mapping of LU changes and urban sprawl has been done in different parts of the world. In Namibia, however, LU and LC classifications so far have only been completed at a national and regional scale.

For administrative purposes, Namibia's land is classified into three main categories, namely State Land, Communal Land, and Commercial Land. Urban and rural areas both can fall under any of these categories. However, it must be noted that these three categories are <u>not</u> LU/ LC classes, but types of ownership.

Statistics show that on a national level agriculture is the major land use class in Namibia. Farming is a major activity for most parts of the country, where by it is carried out as large-scale agriculture or tourism on freehold land and as small-scale agriculture on communal land (Mendelsohn *et al.,* 2002, p. 145). Only a small portion of Namibia, 7200 km² or 0.9 % of the total land, is being used for urban purposes (Mendelsohn *et al*., 2002, p. 145).

LC/ LU change can be subdivided into two major categories, namely conversion and modification. Conversion occurs when one LC or LU class completely changes to another one, while modification refers to changes within one LC or LU class as a result of changes in its physical and functional characteristics (Communities, 2001, p. 45).

Both categories apply to this study, since some parts of the study area have been converted completely into a new class while other parts have experienced minor changes within the same class.

According to Paul *et al*. (1992), at the time of their study; LU mapping was not yet at a stage where up-to-date information could quickly be provided, although satellite imagery was available, but spatial resolution was insufficient. They state that for most areas LC/ LU information was 5-10 years old, hence too old for operational uses (Paul *et al*., 1992, p.439). They use the example of Markham, a Canadian town, for which in 1992 the most recent available maps dated from 1984, and thus LU was mostly outdated (Paul *et al*., 1992, p. 439). This is certainly even more likely for rapidly growing cities in less affluent nations.

2.3 Using Remote Sensing (RS) and GIS to map Land Cover/Land Use

The use of information technologies such as Geographic Information Systems (GIS) and Remote Sensing (RS) for land and natural resources management is widely recognised. These technologies have been proven to provide a cost effective and accurate method for the analysis and understanding of land dynamics (Rimal, 2005, p. 80). Great potential for understanding landscape dynamics lies in the application of digital change detection methods based on multi-temporal and multi-spectral RS data. Furthermore, even LU planners on municipality levels use GIS and RS to carry out land-related activities. There is e.g. a new municipal law in Columbia which requires all municipalities to develop LU plans for the next decade (Gupta & Roy, 2012, p. 105).

"Viewing the earth from space is now crucial to the understanding of the influence of man's activities on his natural resource base over time" (Ohri & Poonam, 2012, p. 12). Sometimes LU change is so rapid to the extent that it is not recorded; in this case observing the earth from space provides accurate information about how humans utilise the landscape (Ohri & Poonam, 2012, p. 12). RS data plays an important role in regional planning and Land Use planning, especially in cases where there are no base data available for a particular area (Communities, 2001). Taking photographs and images of the earth from space provides detailed information about the earth's land surfaces and other resources (Al-Tahir *et al.,* 2005, p. 36).

RS imagery is interpreted and analysed by identifying features or objects that are seen on the image in order to extract useful information about them (Canada Center for Remote Sensing, no date, p. 141). RS-related techniques have been advancing over the years and proved not only to be effective, but also less costly than other methods of data capturing. As a result there has been an increase in the use of computer processing of aerial photographs and satellite images to detect LU change (Al-Tahir *et al*., 2005, p. 36). Comparing images of different time frames with GIS techniques enables the mapping, monitoring as well as studying of LC/ LU change of a particular area. The the importance of GIS and Remote Sensing especially lies in its ability to prepare various input data and for displaying and visualising the results (Sietchping, 2000, p. 557).

Information can only be extracted accurately if the objects are easy to differentiate from other features around them (Canada Center for Remote Sensing, no date, p. 144).

Visual air photo interpretation is based on basic elements such as tone, shape, texture, pattern, site, and spatial association of the features or objects of an area. In the past transparencies were overplayed on hard copy images for interpretation, but nowadays visual interpretation is often combined with on-screen digitizing.

The interpretation techniques and skills required are similar for both approaches though. The output quality of visual interpretation still heavily relies on the interpreter's skills. The level of accuracy directly depends on the knowledge of the interpreter about the landscape which is to be mapped.

Regarding urban sprawl, interfacing GIS technology with RS can provide detailed and accurate data which is beneficial to land planners or any other institution or individual that requires such information (Paul *et al*., 1992, p. 439). Technologies such as RS and GIS therefore can assist greatly in identifying urban growth rates.

When there is a need to speed up certain mapping projects, people usually resort to the use of existing aerial photographs as an effective and inexpensive method of collecting information. Many countries, including Namibia, have used aerial photographs for tasks like census mapping and land registration.

Map series of urban sprawl give a clear indication of where various types of growths occur; they also provide a data base on how future patterns and directions of urban sprawl are likely to look (Saravanan & Ilangovan, 2010, p. 141). These technologies enable processes of detecting, mapping, and analysing spatial as well as temporal patterns of urban sprawl in a cost effective way (Saravanan & Ilangovan, 2010, p. 145).

However, various challenges might be encountered when using RS and GIS techniques for Land Use mapping. Sometimes the spatial resolution of the available data source is insufficient to map some features digitally as they may not be identifiable. Errors like sensor-related and panoramic distortions from satellite data capturing may easily result in features not being represented at their accurate location (Paul *et al*., 1992, p.439).

There are various methods of classifying LC and LU from satellite images or aerial photographs that can all be adjusted to suit the need of a certain research. Different studies on LC/ LU mapping have employed such methods, depending on the size of the area, resolution of the raster data sources available and objectives of the studies. Due to the availability of up to date high resolution satellite and aerial images, various RS and GIS applications are now based on the precise extraction of ground objects instead of regions of certain Land Cover classes (Aminipouri, 2009, p. 3).

The study of Tadesse *et al.* (2004, p. 1) compares pixel image analysis and object-oriented analysis. The pixel image analysis classifies the image based on the spectral information of the pixel (Tadesse *et al*., 2004, p. 1). The accuracy level of the classic pixel- based methods may be limited due to increased spectral within-field variability (Tadesse *et al*., 2004, p. 1). Such methods also have the shortcoming of not being able to classify the image accurately if different objects have similar spectral information. In contrast, object-oriented image analysis uses image objects (segments) as basic processing units instead of single pixels (Tadesse *et al*., 2004, p. 1). Soft classifiers based on fuzzy logic are also used instead of hard-classifiers in this object-oriented approach. Tadesse *et al*. (2004, p. 3) conclude that the object- oriented approach produces a better and accurate classification output than the pixel- based approach.

Finley (2011) argues that using satellite based approaches such as the maximum likelihood to map LC/ LU is a new and better approach. She further argues that such approaches are preferred due to their benefits of covering larger areas and ability to facilitate more efficient analysis.

With these approaches, there is no need to digitize and interpret information since the classified data are compatible with GIS (Finley, 2011, p. 2). However, as this present study will show, satellite-based approaches are only sufficiently accurate if large areas are being mapped, but they do not map small urban/built up areas accurately. On-screen, detailed, unit-by-unit digitizing thus produces much better results in terms of differentiating specific objects.

Gupta & Roy (2012) generated a LU/ LC cllassification scheme based of the Burdwan municipality using the United States Geological survey (USGS) classification system as a reference, in relation to LC/ LU features of the area. Gupta and Roy (2012) were successful in their approach because the USGS classification system enabled them to classify various LC/ LU categories of the whole city in detail.

Although their approach was suitable for their purpose, it was not adopted for this present study of Goreangab which only focuses on a small area but not on the city of Windhoek as a whole.

Paul *et al* (1992) followed a standard per pixel classification whereby high resolution SPOT imagery, GPS data, and LU zoning information were used in conjunction with the existing Ontario Base Map (OBM) data to provide updated Land Use maps. For their study area of approximately 200 km^2 their method it proved to be more suitable than visual interpretation of the aerial photographs. For such a big area, on-screen digitizing of aerial photographs would have been too expensive and time consuming.

Studies like the one of Rimal (2005, p. 81) have used Markov models to analyse LC and LU patterns as well as to predict future LC and LU. Markov process models are a class of probability models to study the evolution of a system over time. If done correctly, Markov models are good for future predictions as the model future Land Uses based on the probability of current LU categories changing from one into another.

Ground surveys are also considered as another way of collecting information about LC/ LU changes. They are considered to be highly accurate because they involve survey crews visiting the sites and recording their observations (Finley 2011, p. 1). Due to the high costs and time involved this method usually is not suitable for generating LC/ LU maps (Finley, 2011, p. 1). Therefore, ground surveys are mainly conducted only to verify the image interpretation, but not as an independent method of collecting LC/ LU data.

Belaid (2003) used the visual interpretation technique supported by the computer. The technique involved the display of georeferenced images to digitize polygons that present different Land Use classes based on their distinct characteristics (Belaid, 2003, p. 5). Ground observations and local knowledge played a major role in guiding the interpretation (Belaid, 2003, p. 6). The final product of Belaid (2003) was a digital coverage layer with polygons representing various LU categories.

Sietchping (2000) used an approach of integrating GIS with Cellular Automatic Models (CAM) to model the expansion of informal settlements in Yaounde, Cameroon. Cellular automation models refers to mathematical models where space is dynamic with discrete time systems (Sietchping, 2000 p 557). Mathematical models may yield good results when it comes to urban sprawl, provided, however, that they are being carried out by knowledgeable persons and in an accurate way.

After comparing the different approaches, the author of this present study opted to neither employ Markov model, pixel-based model, Cellular Automatic Models, nor mathematical models, but a knowledge-based visual interpretation of aerial photographs and predictions based on population projections. This seems especially suitable due to the fact that the study only concentrated on a small area and high resolution aerial photographs were used. Visual interpretation and on-screen digitizing were thus expected to produce more accurate results than any other method. Ground truthing was limited to verify the visual interpretation results of the aerial photographs.

3 Study area

Goreangab is one of the peripheral townships of Windhoek, the capital city of Namibia. The study area is located in the northwest of Windhoek (Figure 1). Goreangab is found in Samora Machel constituency. Based on the 2011 housing and population census, Samora Machel is the second highest populated constituency in Khomas region with 50'110 inhabitants second only after Windhoek West which has 53'438 inhabitants (Namibia Statistics Agency, 2013, p. ii). According to Namibia Statistics Agency (2011), the total number of households in the Samora Machel constituency has increased from 6'598 in 2001 to 13'250 in 2011.

Goreangab thus definitely reflects the population increase of the constituency due to its rapid growth. Consequently, the bigger portion of this area is made up of informal structures which are ever changing and increasing.

It was therefore decided to use Goreangab as a study site, not only because it exhibits some of the highest urban sprawl and population growth rates, but also because it is located right on the urban fringe (Figure 1), so that any change will most likely not only show in changing LU categories, but also in spatial patterns.

For detailed mapping, an area of 1.374 km² to the northwest of Matshitshi Road, a major through-road, was selected (Figures 1, 2).

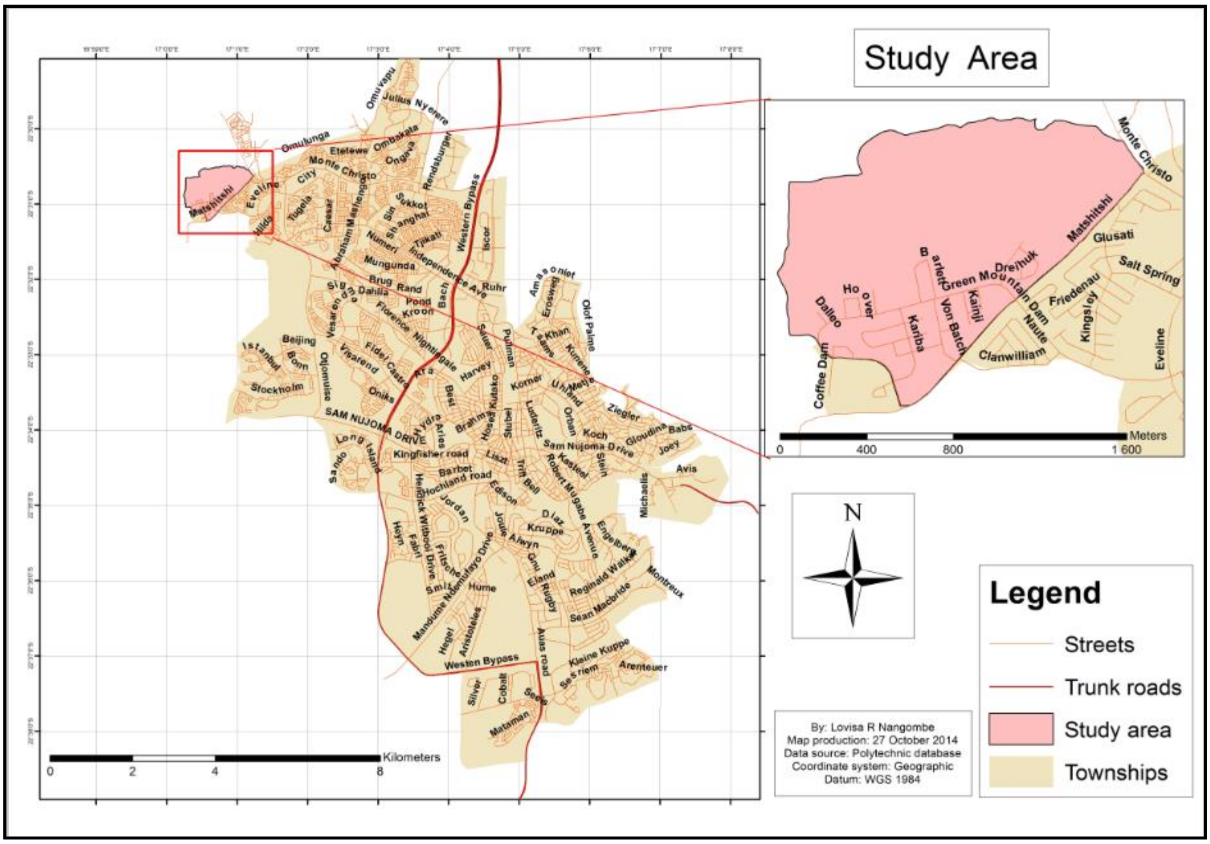


Figure 1: *Location of the Goreangab study area at the northwestern fringe of Windhoek. Data source: Polytechnic digital data base. Map by: L R Nangombe.*

An earlier study of the Goreangab Dam vicinity (Boltshauser & Stengel, 2002, based on field work in 2000) had already investigated the urban sprawl in the northwest of Windhoek. By then, the growth had just about reached Matshitshi Road, but not gone beyond. This present study therefore is able to point out the continued growth of Windhoek, even into the less accessible mountainous periphery.

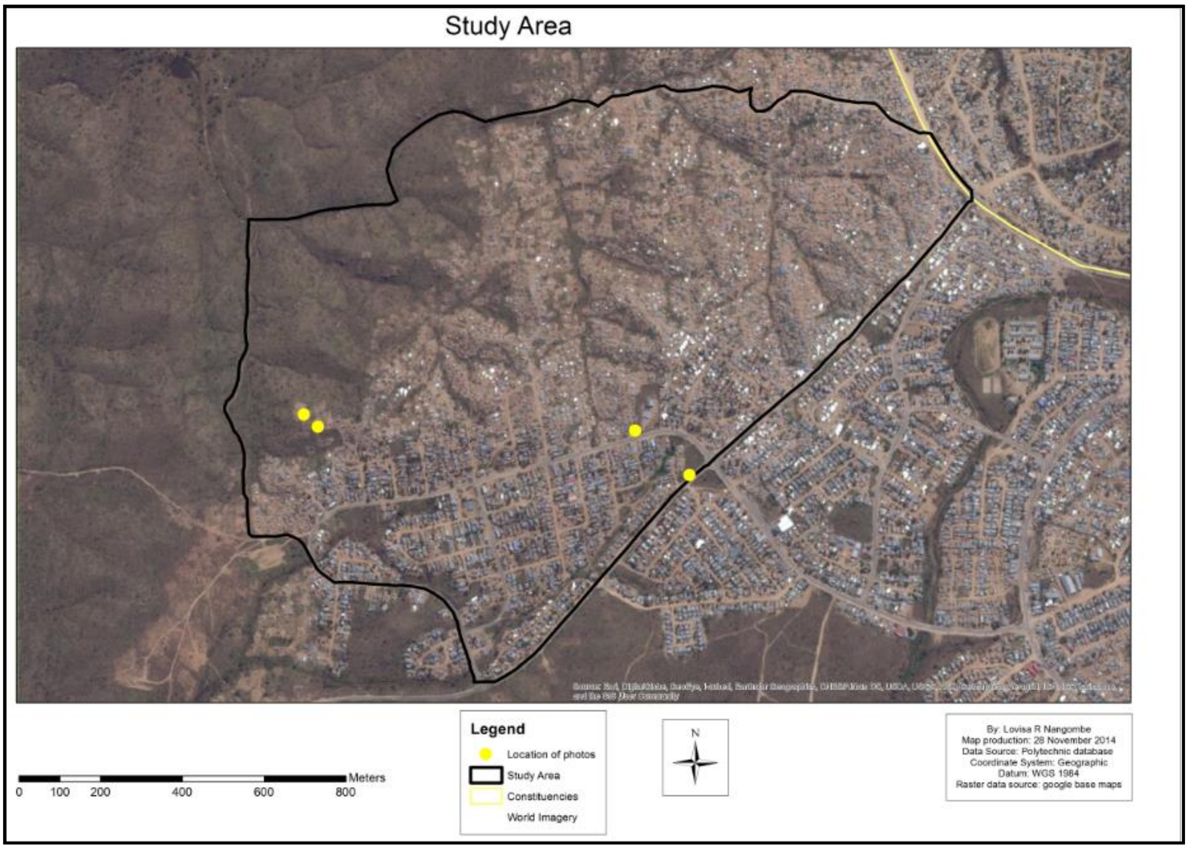


Figure 2: *Goreangab study area outlined on 2013 GoogleEarth™ image. Data Source: GoogleEarth™ world imagery. Location of photos in Figure 3 are marked with yellow dots. Map by: L R Nangombe.*

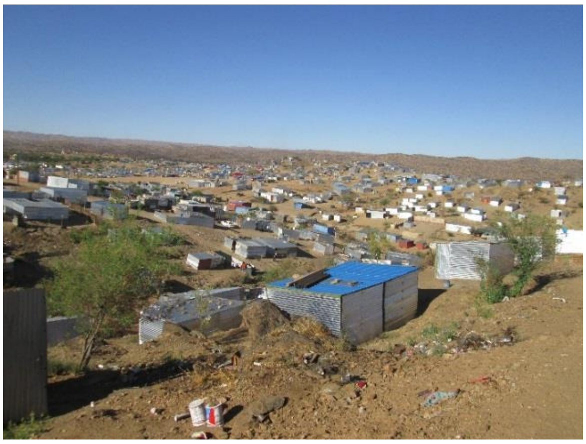
Ground photographs (Figure 3abcd below, for location of photos see Figure 2) show that only a small portion of the study area has formal ervens and proper houses. The much larger portion comprises informal structures made of corrugated iron sheets (Figure 3abc) or even card boxes for inhabitants who cannot afford to buy corrugated iron.

Some inhabitants have no access to basic needs like sanitation, water and electricity. There are shared public water points and toilet facilities in some areas, but they are not sufficient to cater for all the households, since they are too far for some people to reach. Inadequate or non-existent waste disposal sites and lack of municipal waste removal are also typical characteristics (Fig. 3d).

Some residents have resorted to illegal electricity connections that pose a serious danger to the people. Illegal connected cables are usually visible on the surface where they can easily be stepped on or damaged and pose the risk of electrocution. The City of Windhoek carries out routine patrols to disconnect all illegally connected cables; still, residents always find a way to reconnect them.

Incidents of land grabbing and illegal occupation of the municipal land are reported on a monthly basis. In some cases the City demolishes the illegal structures, but do not succeed in demolishing them all, and new structures are continuously being set up.

All these processes are crucial reasons why the *detailed mapping* of structures, from high-resolution aerial photographs instead of from satellite data, is so crucial for urban management and planning.



3A: Overview of part of the study area

3B: Mountainous topography of the study area

3C: Structures expanding into the mountains

3D: Waste dumping next to structures and into the valleys

Figure 3: *Ground photos of the Goreangab study area. The characteristics of an informal settlement such as structures made of corrugated iron sheets and the lack of formal infrastructure can clearly be seen. The settlement continues to grow into the less accessible, mountainous outskirts of Windhoek.*
Photos by L R Nangombe (16/10/2014). Photos locations are marked as yellow dots on Figure 2.

4 Methodology

The methodology chart flow below (Figure 4) illustrates the main steps carried out in this study.

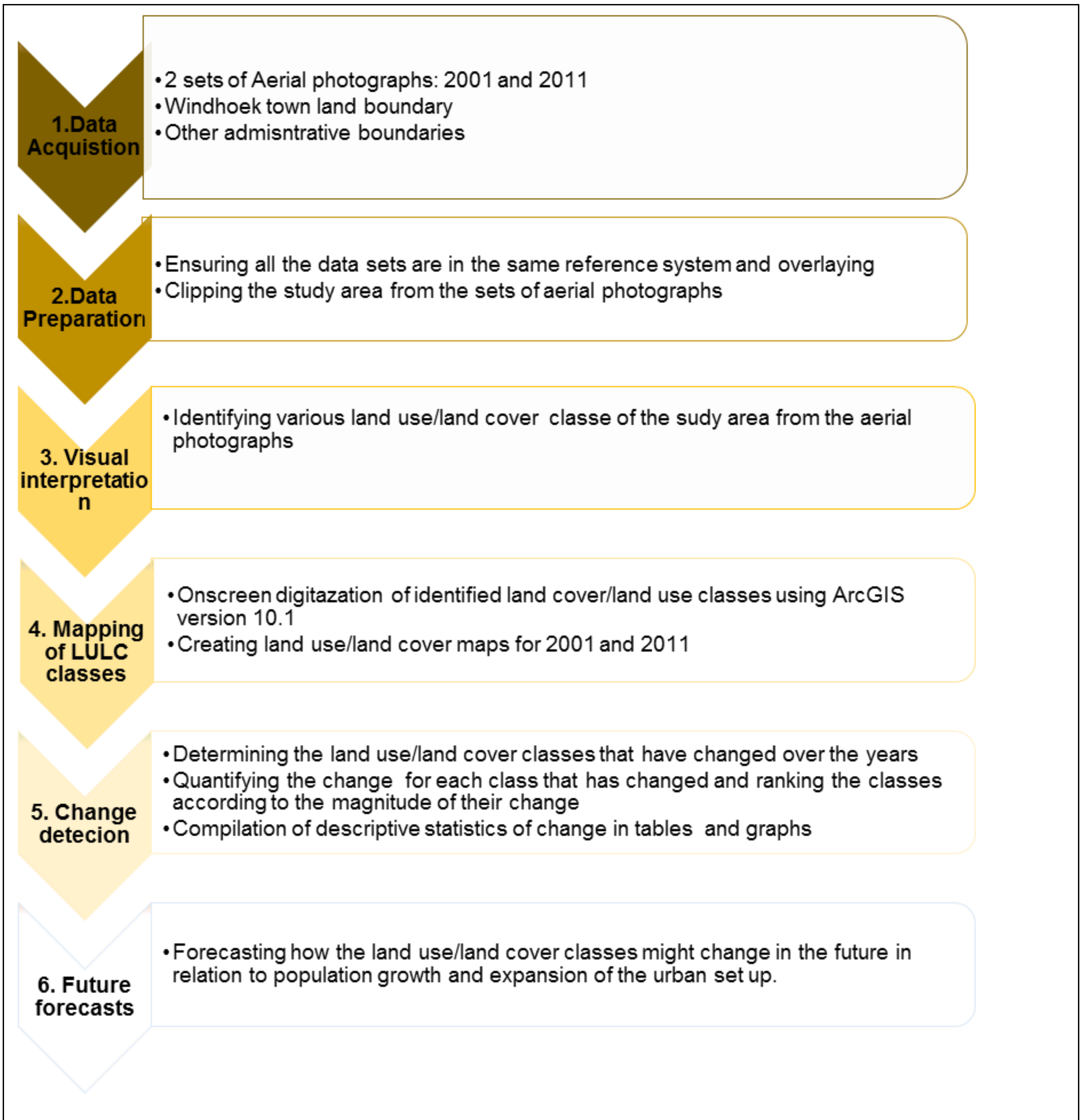


Figure 4: *Methodology chart flow. Design: LR Nangombe (2014).*

4.1 Data collection and preparation

For accuracy reasons, this study adopted a detailed, qualitative mapping method. Two sets of aerial photographs, dating from 2001 and 2011 respectively, were used as information source (no aerial photographs were available in between).The qualitative visual approach was chosen because with it one can overcome challenges like brightness differences and quality of the photography.

The 2011 aerial photographs were taken at a high resolution of 0.5 m and the 2001 ones at 1.5 m. No official aerial photographs of 2013 were available, but only downloaded GoogleEarth™ images which did not retain the original resolution. Digitizing was thus limited to the 2001 and 2011 data sets.

Additional information, vector layers like the Windhoek townland boundaries, cadastral information, ervens, roads, and streets were included in the database for orientation and comparison purposes.

All vector layers and the aerial photographs for 2011 were acquired from the Polytechnic of Namibia's database. The aerial photographs of 2001 were acquired from the GIS division of the Municipality of Windhoek.

After the data compilation, ArcGIS software (version 10.1) was used to verify and ensure that all data were in the same reference system. It turned out that the 2001 aerial photographs acquired from the Municipality of Windhoek were not georeferenced; hence Global Mapper software (Version 12) was applied to georeference them, with the 2011 aerial photographs used a reference base. Aerial photographs from both dates were cropped to the study area to achieve a manageable size of the data set.

4.2 Identification of Land Use (LU) categories

Phase 2 deals with delineating the main LU and LC classes. This study has adopted the interpreter's expertise in interpretation of aerial photographs to identify, interpret and delineate various Land Use and Land Cover classes. It entirely relies on visual photo interpretation skills and knowledge of the study area to distinguish the LU/ LC classes. The used aerial photographs are of a very high resolution, thus most classes could easily be identified, if necessary with the help of ground verification if objects were unclear.

The identified LU/ LC classes were then manually digitised on-screen, based on their different tones, textures and other characteristics. Different features were digitised in different layers as points, lines, and polygons. Areas comprising barren land or other features irrelevant for this study were not mapped, but left as a semi-transparent background layer, in a visualization technique adopted from LU mapping in similar, semi-arid environments of Sudan (Meissner & Ripke, 1993, map examples)

The following LU categories were identified and then adapted for the study area (Table 1).

Category	**Description**
Structures	Houses, shacks for residential and other purposes
Incomplete structures	Houses that are still being built or shacks that are still being set up.
Small bathrooms/ business stalls	Outside bathrooms used by people living in shacks or small roadside business stalls.
Net shades	Mainly used as shelter for vehicles.
Transportation networks	These are paved roads or streets, unpaved roads or streets and tracks.
Big trees/bushes	(I) Big trees that have been there since 2001 and were never cut down, (ii) or trees which have grown between 2001 and 2011
Property enclosures	Boundaries which mark off properties either in a form of a fence, cardboards, or in the form of small bushes.
Image background	The image background was left as it is where there are no significant land use classes

Table 1: *Adapted Land Use categories for the Goreangab study area.*

Several challenges were encountered during mapping, e.g. being unable to differentiate objects from each other due to size or shape. In some instances even ground verification could not help with such challenges as the situation on the ground has already changed since the most recent aerial data were captured. Such challenges will be discussed further in the results and discussions section.

5 Results and discussion

The results of the detailed LU /LC mapping discussed below refer to several categories:

(a) Observed overall changes in LU/ LC;

(b) Specific changes referring to Structures, Trees, and Roads;

(c) Possible future implications.

For easier reference, the mapped area was divided into grid blocks, numbering A through E (west-east) and 1 through 4 (north-south).

Note that all the maps were produced to fit an A3 format. Maps presented in the text had to be reduced in size.

5.1 Overall changes

The analysis of the two dates (2001 and 2011) indicates extensive changes, both in terms of both LC and LU (Figures 5, 6, 7).

For the full resolution, please refer to the three A3 format maps in the Appendix.

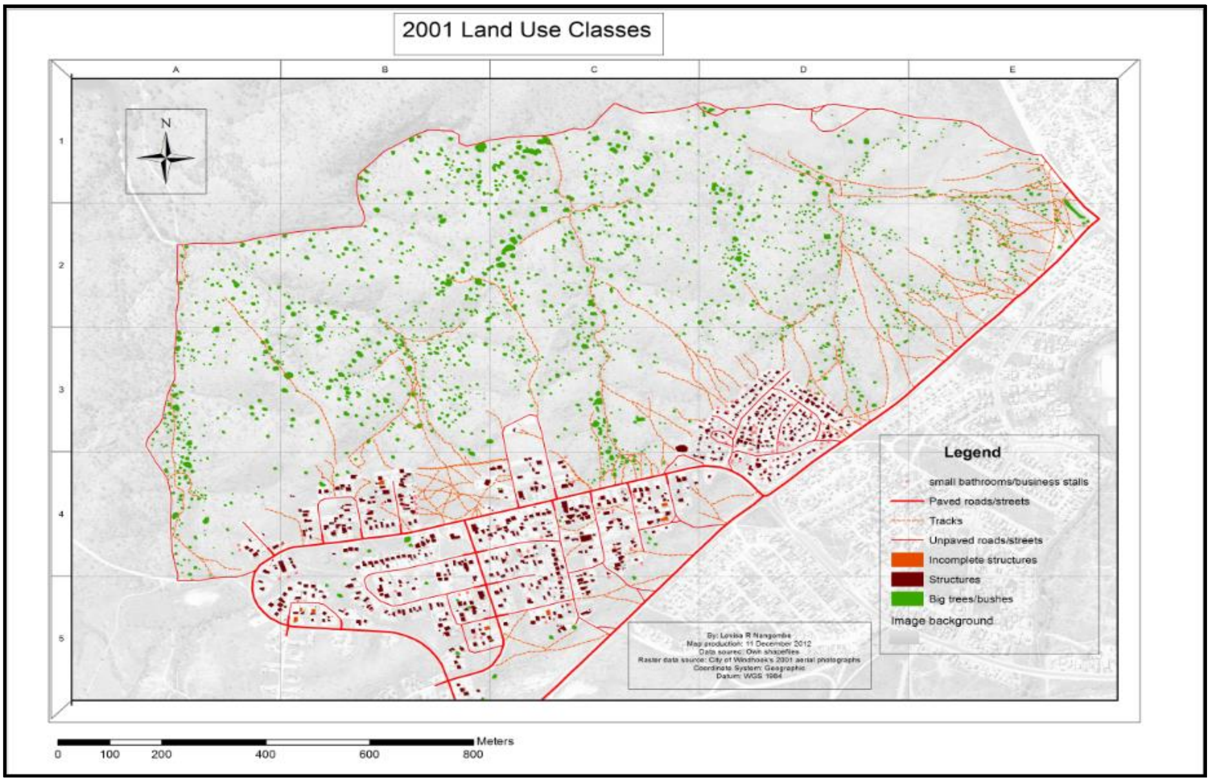


Figure 5: *Land Use categories of 2001. Data Source: City of Windhoek Municipality aerial photographs of 2001. Analysis and map by: L R Nangombe (2015)*

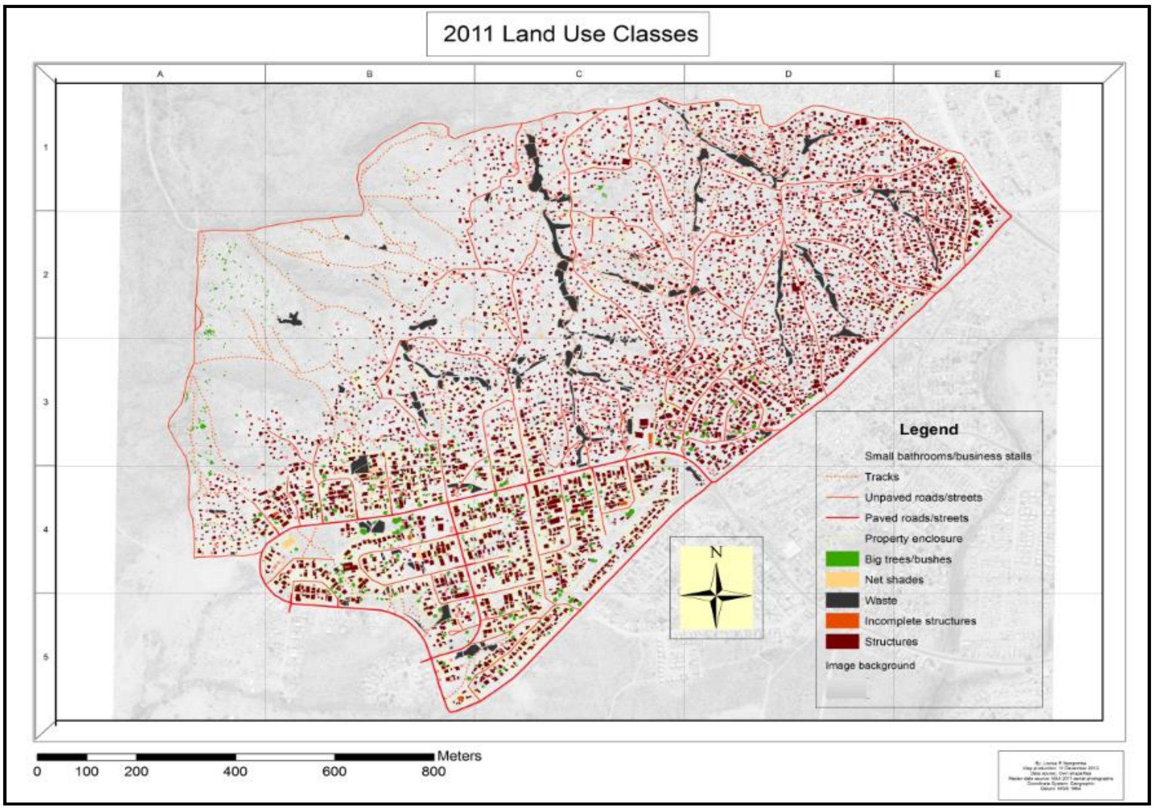


Figure 6: *Land Use categories of 2011. Data source: 2011 Windhoek aerial photographs. Analysis and map by: L R Nangombe (2015)*

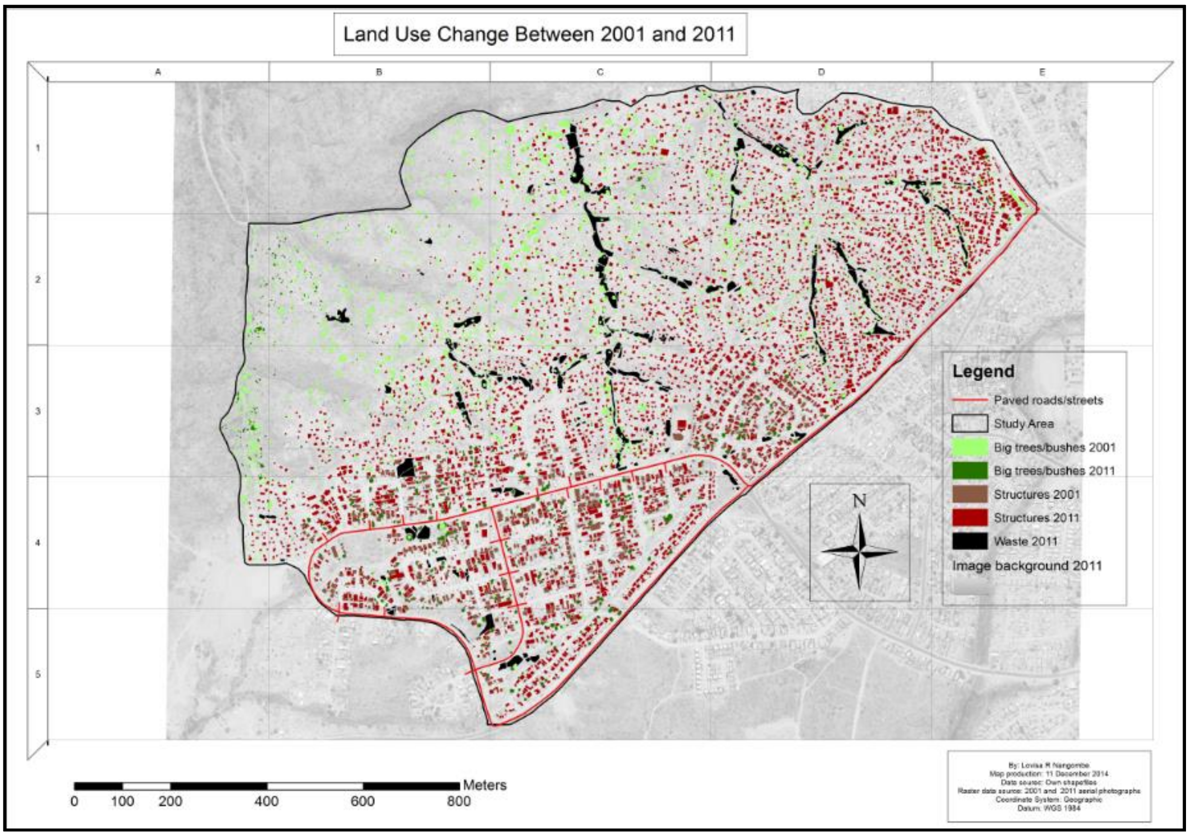


Figure 7: *Land Use change in Goreangab 2001-2011. Data source: 2011 Windhoek aerial photographs. Analysis and map by: L R Nangombe (2015)*

LU classes which already existed in 2001 like Structures, Small bathrooms, Trees, Roads and tracks have changed in two ways: their individual numbers have grown considerably, and the total area covered by these categories has thus increased as well.

There were also several new LU classes in 2011, namely (i) Net Shades that are used to provide shades for parked vehicles, (ii) more Property Enclosures that demarcate properties either by fences or small planted bushes. This means that the land in that area is now in higher demand than before and people are enclosing off their properties to ensure that they are not occupied by new dwellers.
In 2001 (Figure 5), only a small portion of the study area was covered by man- made features. These man- made features mainly covered blocks: A4, B4, B5, C4, C5 &D3 in 2001. By 2011 (Figure 6), the human made features have spread almost all over the study area. An outward spread of structures towards the still vacant land is evident. This trend is expected to continue in future as the growth of the informal settlement goes on.
On both data sets, numerous incomplete structures could be identified. This is an indication that LU is always changing in this area as there are new structures being built literally on a weekly basis.
Since 2011 there has been an increase in unregulated waste dumps. These dump sites could be identified and mapped in most parts of the study area. Since a central waste disposal facility or collection sites are missing, some dump sites are very close to, and/or between structures used for residential purposes. The close proximity of living space and waste dumping poses major problems for health and water quality.
The increased numbers and sizes of dump sites in 2011 (192 sites) highlights that problems of waste management have escalated since 2001, as Windhoek Municipality is faced with a challenge of providing such services to all the ever looming informal settlements.
As a result of all these changes, the whole study area has been completely transformed within ten years. The most visible and drastic changes are visible in the informal area which constitutes 90% of the study area.

No doubt urban sprawl is rapidly taking place on this side of the city. There has been a proliferation of informal settlements in Goreangab over the past 10 years and it is still continuing at a very high rate. This is expected since urban sprawl generally takes place at the fringes of cities to accommodate their population growth.

The overall changes mapped in the study area are summarized in Table 2.

Land cover class	No. of mapped units in 2001	Area covered in 2001 [m²]	% of study area in 2001	No. of mapped units in 2011	Area covered in 2011 [m²]	% of study area in 2011	Change in numbers	Change in area
Structures	639	23857.9	1.7 %	4906	137970.1	10%	4267 units	114112.2 m²
Big trees/ and ,bushes	1877	52006.2	4 %	626	13528.4	1%	1251 units	38477.8 m²
Bathrooms, stalls	100			885			785 units	
Waste	--	--	--	192	35391.5	3%	192	

***Table 2**. Changes in numbers and spatial extent of Land Cover categories from 2001 to 2011.*

5.2 Mapped changes of Land Use (LU) categories

This section shows in more detail some of the mapped LU categories. Note that the subsequent maps do not portray the whole study area, but smaller subsets only, simply for clarity reasons. The full extent of change can be viewed from the digital data sets, of course.

5.2.1 Land Use (LU) category conversion

The drastic changes in LU become especially evident if small subsets of the two dates 2001 and 2011 are compared in detail.

For many areas, a complete conversion of LU has taken place – the previous LU type has completely been transformed into new functionality.

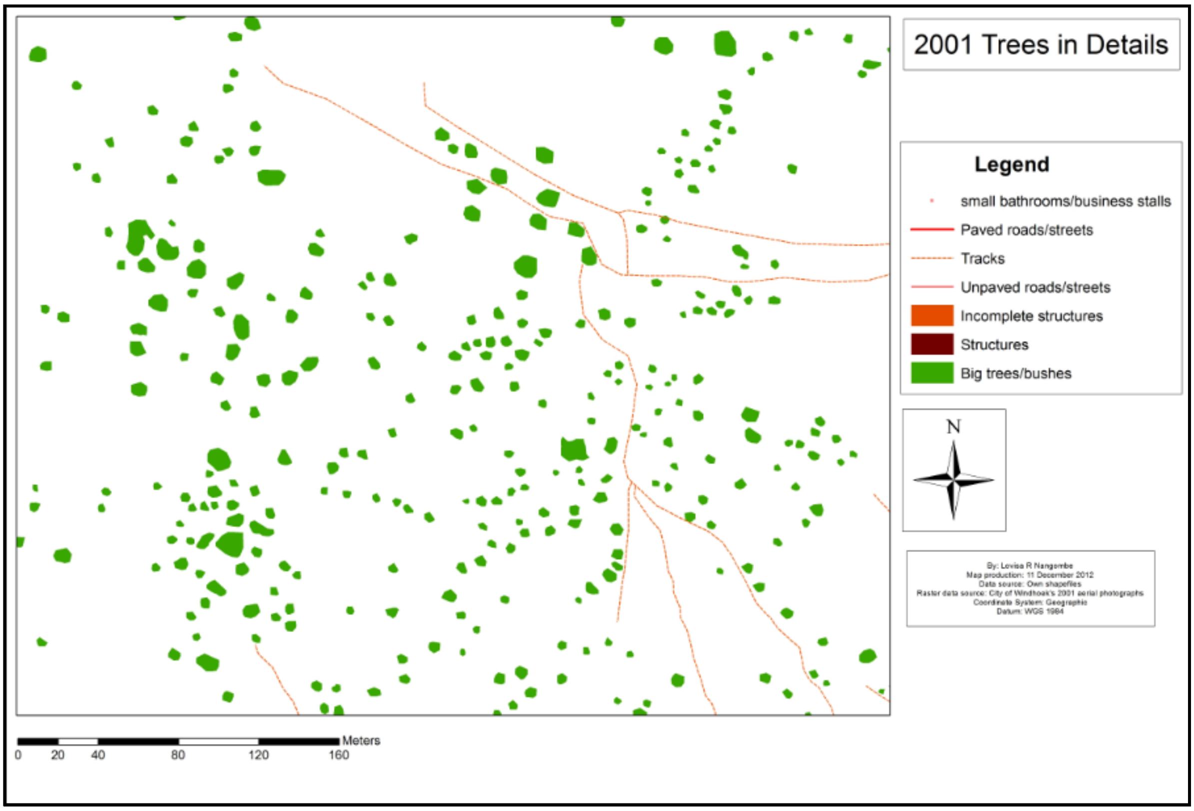


Figure 8*: Area showing trees and tracks only (2001). Data source: City of Windhoek Municipality aerial photographs of 2001. Analysis and map by: L R Nangombe (2015)*

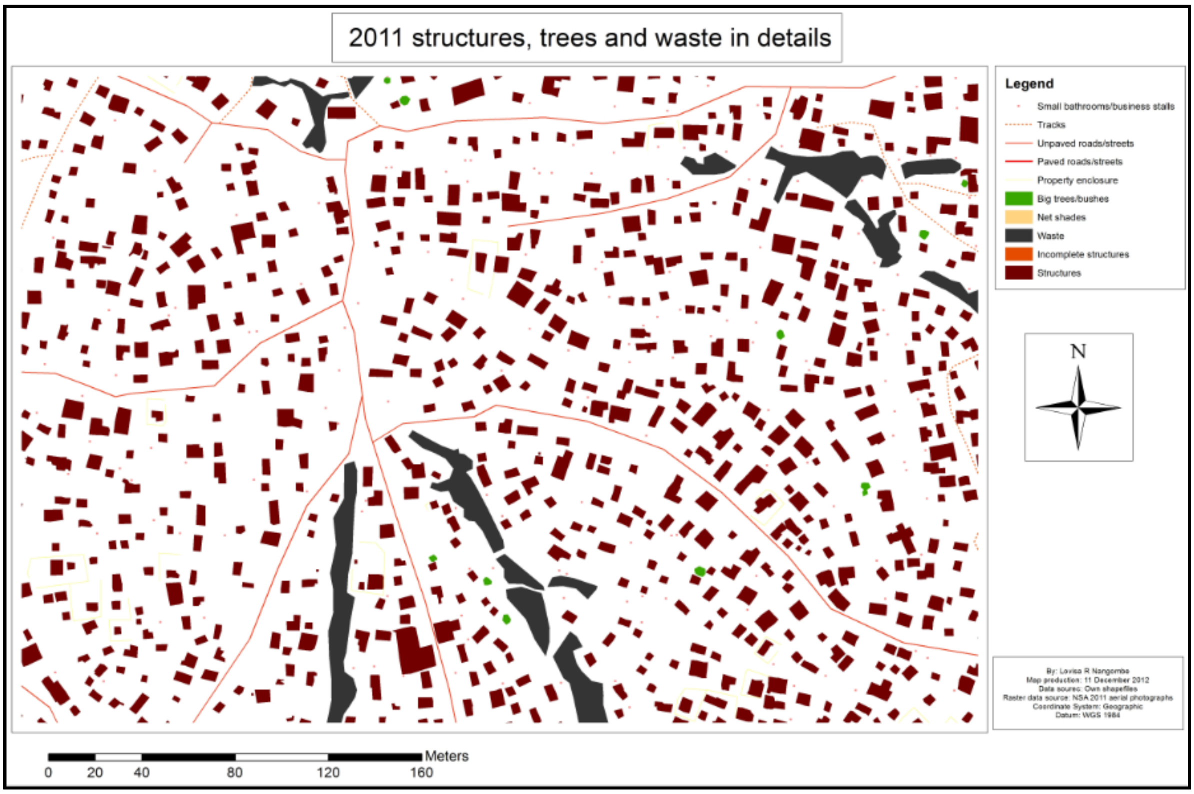


Figure 9*: Same area covered by structures, waste and unpaved roads (2011). Data source: 2011 Windhoek aerial photographs. Analysis and map by: L R Nangombe (2015)*

A large portion of the study area still covered by trees and bushes in 2001 (Figure 8) looks completely different in 2011 (Figure 9). Vegetation has now been replaced by thousands of (4907) man-made structures. The majority of these structures are used for residential purposes. Some are used for small scale commercial purposes or as outside bathrooms and there are (885) of these small structures in 2011.

Even the part of the study area which in 2001 already was covered by formal houses has changed until 2011 due to the fact that people have extended their houses, and more new houses have been built.

A total of 4267 new structures were built between 2001 and 2011 (Table 2 above), keeping in mind that the total area only comprises 1.374 km². The overall percentage by structures has thus increased from 1.7 % of the total study area in 2001 to 10% in 2011.

5.2.2 Changes in the Tree category

Figure 10 shows how the area covered by big trees and bushes have decreased since 2001.

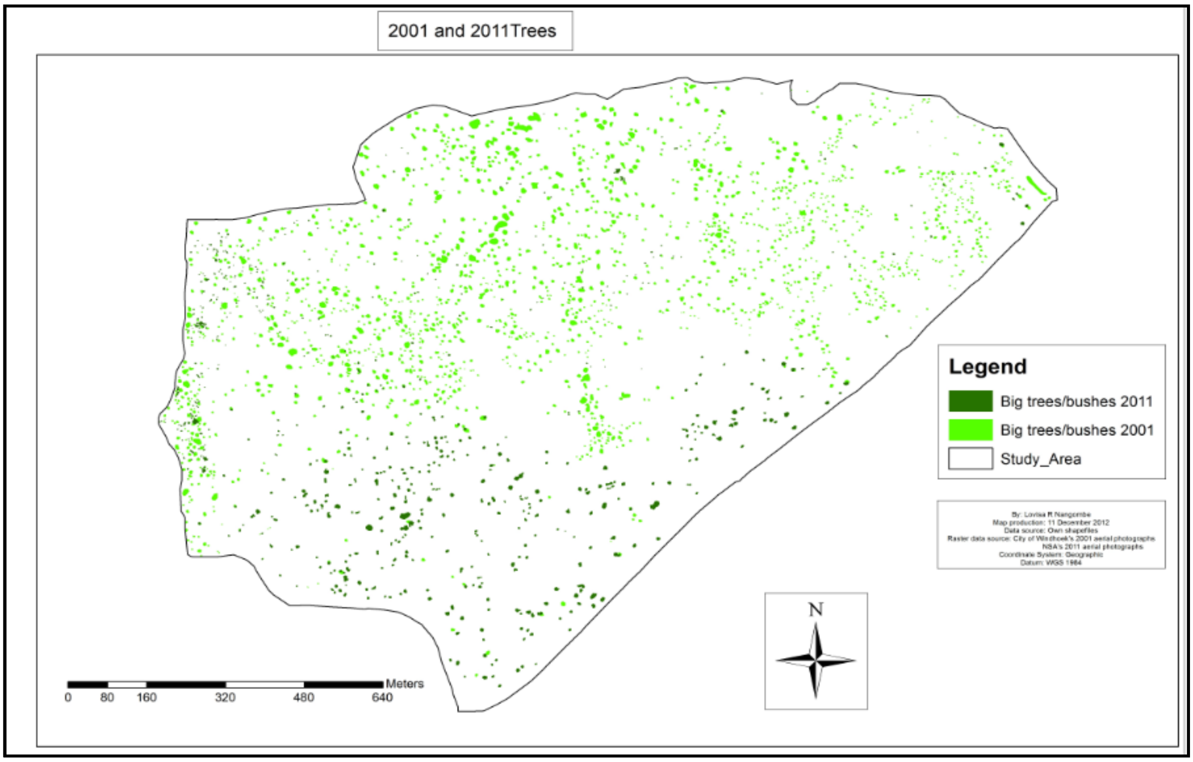


Figure 10: *Decrease of tree coverage from 2001 to 2011. Data Source: 2001 and 2011 Windhoek aerial photographs. Analysis and map by: L R Nangombe (2015)*

In 2011, only a few trees were still visible in the northern eastern and northern western sides of the study area. Respectively, the area covered by trees decreased from 52'006.2 (4% of the study area) in 2001 to 13'528.4 (1 % of the study area) in 2011 (Table 2).

Most big trees had been cut down as more land was cleared in order to put up structures.

Especially smaller trees, bushes and shrubs were eliminated; ground experience shows that this is mostly due to cutting of firewood and some use for fencing and construction as well (see also results of Boltshauser & Stengel, 2002).

The surviving trees, which indicate some persistence of spatial patterns, are mostly *Acacia mellifera* and some Camelthorn (*Vachellia erioloba*) trees which were big and high enough to be used as shade by vendors selling small items or even as shade for parked vehicles.

New trees also were detected in some parts of the study area because they were not present in 2001. Their number (252 trees) is however negligible compared to the overall loss of vegetation.

5.2.3 Changes in the category of Transportation (paths and roads)

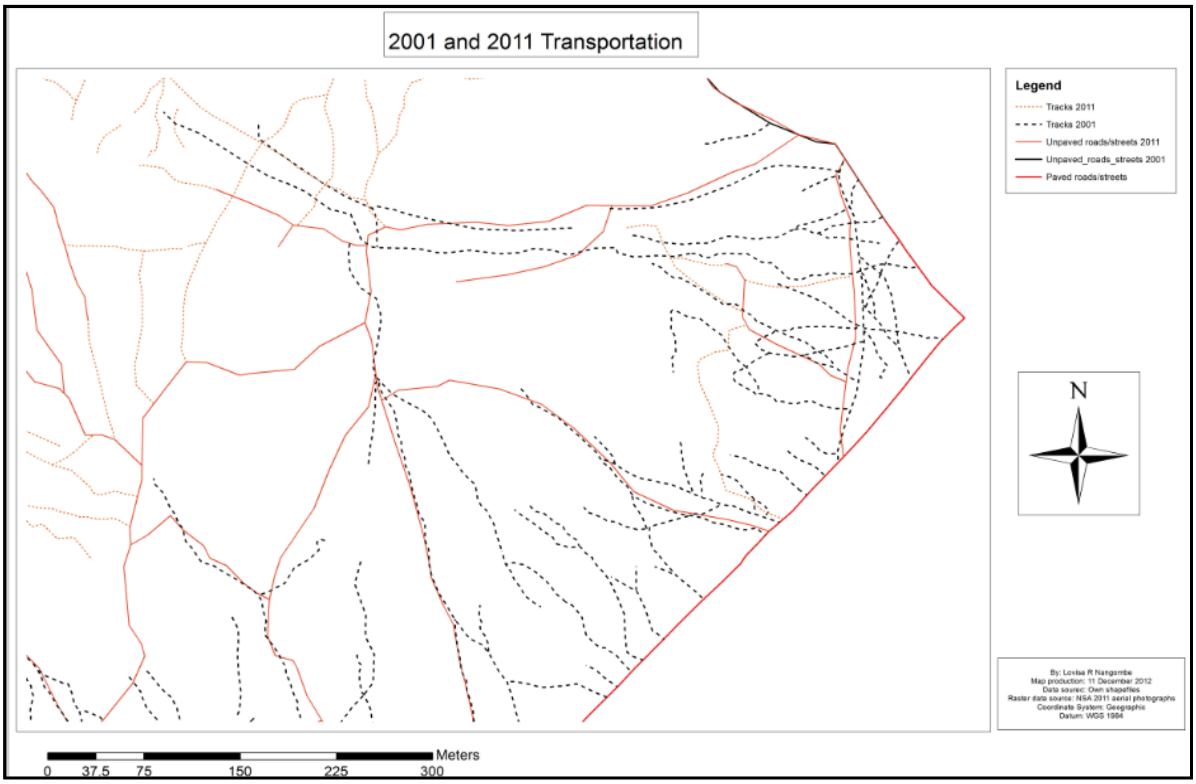


***Figure 11**: Transportation network changes from 2001 to 2011. Data Source: 2001 and 2011 Windhoek aerial photographs. Analysis and map by: L R Nangombe (2015)*

The change in the network of paths and roads exhibit several different spatial trends (Figure 11):
(a) Many existing unpaved tracks which were only used by pedestrians in 2001 have developed into unpaved roads by 2011 and are now also used by vehicles (Figure 11). This means that even though the paths originally formed by pedestrians, their position has remained the same over the ten years, but their function has been changed and adapted.
(b) Many more new tracks have been developed to cater for the increasing population of the area. This is especially visible towards the margins of the built-up area. With increased density of the built-up area, the network of unpaved tracks has been expanded towards the margins and towards the outside.
It can be expected that with increasing population growth, in future this trend will continue: old tracks becoming upgraded and turning into roads, and new tracks forming towards the margins of the area, and beyond.
(c) In some parts, old tracks have been destroyed and replaced or blocked by other land use categories like new structures. Their original function has thus been lost.
(d) The amount and density of paved roads and streets did not change much because the Municipality does not really construct new roads in informal settlements. This means that paved surfaces are likely to be the most persistent land cover categories in a township.
(e) In some parts of the study area, roads are basically missing, thus vehicles cannot reach there. This is attributed to two reasons: (i) Some structures were built so close to each other that there was no space left, or provided, for vehicles – indicating the rapid and unplanned growth and settlement dynamics. (ii) Some areas are inaccessible by vehicle simply because they are too hilly, too steep or in valleys, ravines, and floodplains – again indicating the lack of planning and the dire need of more living space if such places are populated despite the unsuitable topography.

5.2.4 Importance and challenges of mapping Small Structures

From 2001 to 2011, the number of tiny man-made structures multiplied from 100 to 885. These structures are mostly bathroom sheds or commercial stalls.

As the residents of the informal settlements do not have proper bathrooms due to the nature of their houses, they mostly put up tiny sheds outside the main structure (house) to be used as bathrooms. The number of such outdoor bathroom sheds has increased considerably, reflecting the increased population numbers.

However, in many places, tiny structures other than outdoor bathrooms were set up over these 10 years, which mostly are used as small stalls for commercial purposes, sometimes as sheds or for undefined functions.

The differentiation between bathrooms (small, square shaped) and commercial stalls and booths (small, square to rectangular) was not generally possible, in spite of the high spatial resolution of the aerial photographs (Figure 12). An indication would be the position of these tiny structures: stalls usually – but not always – would be along roads, whereas bathroom sheds usually – but not always – would be away from roads and near main structures.

Due to the large number of them ground check for verification unfortunately was not possible, so they were classified as one category despite their contrasting functionality. This was done for two reasons:

(a) For both types of functionality, not only the area which these tiny structures cover, but also the surrounding space usually is highly frequented and compacted.

(b) All these tiny structures, irrespective of their function, contribute to the highly increased number of man-made features, and, consequently, to the decreased percentage of original land surface.

Figure 12: *Outside bathrooms and stalls of street vendors in 2011.Data Source: 2011 Windhoek aerial photographs. Analysis and map by: L R Nangombe (2015)*

5.3 Some geographical and environmental implications of mapped Land Use (LU) changes

5.3.1 Increased number of structures

The increasing number of informal structures reflects the increasing population. From a town planning point of view, it also means that the higher the number of structures (and thus population), the more likely there are health and environmental problems.

From a GIS and mapping perspective, this is not only reflected in the overall number of structures, but especially in observations pertaining to hygiene and accessibility. This is yet another reason why the detailed mapping of the waste heaps, outdoor bathrooms, and road and paths network as conducted in this study is so crucial.
The lack of accessibility by vehicle was already discussed in 5.2.3. Since there are no proper ervens in most informal settlements, the shacks are put up in such a way that if one catches fire the whole neighbourhood is likely to catch fire. This poses a great danger because it is also very difficult for fire fighters to put out fire in such areas.
Based on these high-detail mapping results, GIS techniques can easily be used to calculate average or local density and spacing of structures, or to establish mininum safety distances, depending on the respective need or administrative requirements.

5.3.2 Increase of sealed surfaces

The increase of the number of structures means that more and more of the original land surface is now covered and thus, sealed. The figures of the two categories, built-up Structures and Trees (Table 2, above), are visualized in Figure 13, to illustrate the dramatic shift from 2001 to 2011.
In just 10 years, the original surface which could absorb rainfall water has decreased drastically, while, at the same time, additional water from all the new structures, sealed surfaces, roofs, and paved areas, is now fed into the area and must be absorbed or drained away.

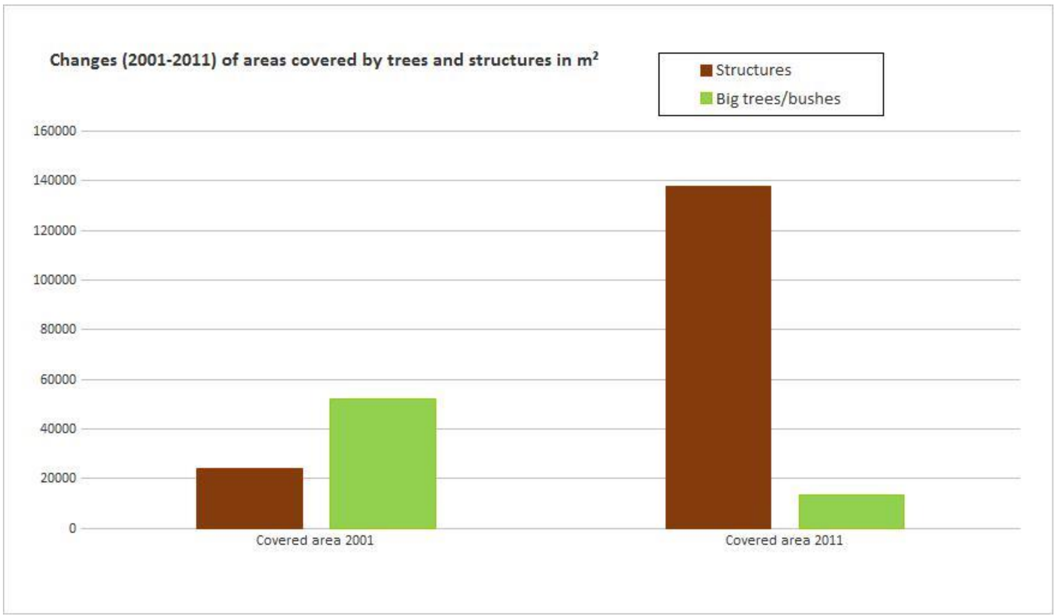


Figure 13: *Shift from predominant tree cover to dominance of man-made structures from 2001 to 2011. Data source: own mapping (see also Table 2)*

While infiltration rates of natural surfaces are controlled by soil characteristics and the level of soil saturation, the ways in which humans have altered the land use and increased the percentage of sealed surfaces, changes the hydrological processes enormously.
When infiltration is reduced to very low levels because of physical barriers such as thousands of structures; there is an additional risk of surplus water runoff from the area. This in turn causes immediate hazards such as erosion, flooding and contamination (e.g. by erosion of waste heaps).
Also, given the hilly topography of the area, runoff can easily pile up to flood waves and fatal danger to people crossing a valley or a ravine.
The amount of danger can be illustrated from the increased spatial extent of Structures from 23857.9 m² in 2001 to 137970.1 m² in 2011 (Table 2 above), hence an increase in sealed surfaces of 114112.2 m² on which no infiltration can take place. These 114112.2 m² thus cause additional runoff at dangerous levels.

Given the average rainfall in Windhoek of 350 mm/ year (Mendelsohn *et al*., 2002, p. 84), the following calculation can be made:

[i]	1 mm rainfall/ year.............................	represents 1 litre rainfall per m²
[ii]	114112.2 m² additional surface on which no infiltration can take place......	represents 39'939'270.0 litres of additional water or 3993.972 m³ (cubic meters) of rainfall water

This means that additional runoff from roofs alone creates almost 4000 m³ of additional water in the study area, even in a normal rainy season. If an exceptional rainy season happens, such as in 2004, 2008, 2009, 2010, 2011 and 2012, these figures can multiply.

One must also keep in mind that even tiny Structures prevent local infiltration due to compaction and frequency of usage. Also, the increased numbers of Paths and Roads, even if unpaved, promote additional runoff as the path usage causes compaction and prevents infiltration even on a dirt road.

In the past, the previously existing trees and even small shrubs and bushes used to counteract the erosion damage and also intercept some of the rainfall water. The significant decrease in the Trees category (Table 2 above) means that less interception and even less protection is now available.

The spatial dimensions of this process must be kept in mind. The more the informal settlements grow towards the city outskirts, the higher the risk of environmental problems affecting large areas. Areas at the northwestern fringe of Windhoek have always been targeted by settlers for new housing - involving the clearing of vegetation, extraction of other natural resources such as sand for construction purposes, increase of uncontrolled waste-dumping and contamination. While the process of urban-fringe desertification in the overall Goreangab area has been described by Bolthauser & Stengel (2002, p. 209), the current detailed mapping has certainly highlighted the urgency of such environmental problems.

5.4 Future predictions

Table 3 below shows that the total population of Khomas Region is projected to increase from the current population of 340'997 inhabitants to 496'546 in 2021. This means an increase by approximately 155'000 people in the next seven years alone.

Although the population projections are only done for the regional level, Samora Machel Constituency is likely to contribute significantly to the growth as it is the second most populated constituency in Khomas Region.

Goreangab Township, in turn, being the most populous township of Samora Machel Constituency, will thus continue to play a major role, as could already be established by the detailed mapping in this study.

Table 3.9 Khomas Projected Population by Sex, Growth Rate and Components of Growth, 2011-2041

Year	Total	Male	Female	Exponential Growth Rate	Sex Ratio	Births	Deaths	Net Migration
2011	340 997	169 550	171 447	–	0.99	10 330	2 522	6 228
2012	355 250	176 517	178 733	4.095	0.99	10 812	2 584	6 229
2013	369 894	183 681	186 213	4.039	0.99	11 252	2 634	6 227
2014	384 893	191 008	193 885	3.975	0.99	11 655	2 672	6 229
2015	400 191	198 475	201 716	3.898	0.98	12 021	2 716	6 227
2016	415 780	206 090	209 690	3.821	0.98	12 352	2 756	6 228
2017	431 607	213 810	217 797	3.736	0.98	12 644	2 799	6 226
2018	447 636	221 626	226 010	3.646	0.98	12 879	2 848	6 226
2019	463 823	229 514	234 309	3.552	0.98	13 076	2 894	6 224
2020	480 136	237 455	242 681	3.457	0.98	13 231	2 927	6 225
2021	496 546	245 442	251 104	3.361	0.98	13 358	2 968	6 222
2022	513 044	253 466	259 578	3.269	0.98	13 450	3 010	6 223
2023	529 572	261 502	268 070	3.171	0.98	13 508	3 052	6 222
2024	546 130	269 550	276 580	3.079	0.97	13 544	3 099	6 223
2025	562 693	277 595	285 098	2.988	0.97	13 572	3 144	6 220
2026	579 247	285 638	293 609	2.899	0.97	13 592	3 190	6 220
2027	595 797	293 672	302 125	2.817	0.97	13 611	3 244	6 218
2028	612 343	301 703	310 640	2.739	0.97	13 617	3 291	6 218
2029	628 865	309 722	319 143	2.662	0.97	13 628	3 347	6 216
2030	645 355	317 716	327 639	2.588	0.97	13 644	3 410	6 216
2031	661 834	325 699	336 135	2.521	0.97	13 684	3 472	6 217
2032	678 307	333 676	344 631	2.459	0.97	13 750	3 546	6 218
2033	694 781	341 652	353 129	2.400	0.97	13 834	3 618	6 217
2034	711 271	349 620	361 651	2.346	0.97	13 926	3 693	6 218
2035	727 788	357 595	370 193	2.296	0.97	14 028	3 782	6 218
2036	744 335	365 573	378 762	2.248	0.97	14 145	3 859	6 218
2037	760 923	373 571	387 352	2.204	0.96	14 280	3 955	6 218
2038	777 544	381 574	395 970	2.161	0.96	14 417	4 051	6 218
2039	794 203	389 591	404 612	2.120	0.96	14 554	4 152	6 218
2040	810 898	397 620	413 278	2.080	0.96	14 696	4 254	6 218
2041	827 619	405 657	421 962	2.041	0.96	14 832	4 361	6 218

Note: "– " Means Not Applicable

Table 3: *Population Projections for Khomas Region. Source: Namibia Statistics Agency (2014).*

The overview comparison of 2013 GoogleEarth^{TM} images with the 2011 aerial photographs shows that since 2011 yet more new structures have been put up in the study area.

Even though the latest available GoogleEarth^{TM} images date from 2013, hence only two years after the data set used for mapping, striking differences to the 2011 aerial photographs could already be identified (Figure 14 below).

- The spatial trends discussed in Sections 5.1, 5.2 and 5.3 are continuing in that the number of structures is ever more increasing.
- The outward expansion trend towards the mountains is even more visible.
- The Goreangab Township is expanding even further into the direction of the mountains.
- Also, existing structures have grown considerably in size and, most likely, permanence.

The sprawl is likely to continue until it reaches the mountains or until the Municipality puts into place measures to control illegal occupations of land. Environmental and health problems are also likely to increase in this area as the population grows, density of structures, fire hazard, numbers of uncontrolled waste dumps increase, infiltration decreases further, and with it all the problems of erosion, contamination and even loss of life.

2011	2013
	
	

Figure 14: *Comparison of 2011 and 2013 structures. Air photo sources: 2011 Windhoek aerial photographs and matching 2013 GoogleEarth™ images*

The comparison between the GoogleEarth™ 2013 images and additional ground truthing carried out in 2014 shows that all of these trends continue at an increased speed.

Some parts of the study area already have changed drastically once again, even within a period of one year.

6 Conclusions and recommendations

This paper aimed to assess whether major changes have taken place in the study area within a period of ten years, and to provide a methodology to also identify such changes by mapping LU on a detailed level by using on-screen digitising and image interpretation skills instead of software based classification methods.

As a result the following overall conclusions are presented:

- Mapping LU and LC by on-screen digitising is best suited for mapping small built up areas on a more detailed scale.
- Urban sprawl in Windhoek mostly takes place on the periphery of the city where several informal settlements are located. e.g. the Goreangab study area.
- The population growth in this area is attributed to the migration of people from rural areas to Windhoek in search of jobs and better living. As they cannot afford decent accommodation, they settle in informal settlements.
- LC and LU the study area literally may change from week to week. Significant changes which occurred between 2001 and 2011 and up to date can be easily identified.
- The population of the area is still growing, man-made structures are increasing, and therefore LC and LU continue to change.
- All administrative, logistical and environmental problems associated with urban sprawl are also on the rise in this area.

Based on the results of this study, the author recommends the following action for the study area and beyond:

- Detailed LC and LU mapping should be done for the whole City of Windhoek, and on a regular basis, so that there is more and up-to-date information available - as there is none at the moment.
- The Municipality should then use such detailed information to plan how to overcome the challenges associated with urban sprawl and the looming of informal settlements.
- The Municipality should demarcate proper ervens for residents of the informal settlements since they will always settle there even if the land is not legally theirs.
- The Municipality should provide basic services such as waste collection, water and electricity for the residents of informal settlements.

From a methodological point of view, the following action is recommended:

- Based on the realization that changes occur at a high speed but at a local scale, it is not advisable to use overview mapping only, but carry out detailed capturing of structures, roads, and other categories of interest.
- This must be based on high resolution data sets, to avoid errors in identifying objects.
- Skilled, knowledge-based digitizing of identified objects is preferred, to accurately monitor present and predict future changes.
- A record must be kept of all parameters (e.g. georeferencing parameters, resolution, software), to allow for easy updating of data bases, even by different users.

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