Drivers of land use change in the Drakensberg Mountains, South Africa.

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Abstract

Change in land use has had major impacts on natural resources. Mountain terrains and their associated natural resources are especially vulnerable to extensive changes in land use. We evaluated climate, demographic and socio-economic changes for two study areas in the Drakensberg Mountains, as possible drivers of land use change in each study area. The most notable change in land use within the study areas was the increase in urban areas despite the fact that the study areas are located within areas dominated with primary economic activities. Trends in climate change were not consistent between the various weather stations with the majority of the weather stations experiencing no significant changes in temperature and rainfall. Although there was a relatively slow positive population growth in the two study areas, it was not a main driver of the changes in land use. We found that socio-economic factors, including increased formal employment, income and migration to urban centres were much more important in driving land use change in these rural environments.

Introduction

It is critical to understand drivers inducing land use since land use changes are occurring worldwide, threatening natural resources (Lambin 2001; Zeleke and Hurni 2001). Land is a finite resource required by all activities (food production, residential, recreational, industrial etc.). Understanding characteristics of land use changes (i.e. changes in demand and priority, and/or forced changes) is key to anticipating future changes and developing mitigation strategies (Zeleke and Hurni 2001).

Mountainous areas play an important role in society; they have cultural significance and sustain the daily life of communities in a unique way (Sharma 2012). Nearly a tenth of the global population depend on mountains for their daily provisions whilst the provisions for almost half of the global population are linked to mountains (Ives 1992). Mountain landscapes vary greatly and can be characterised by various land uses depending on the culture, habits and demands of the surrounding communities (Soliva et al 2008).

Thorough research into development in mountain areas is often compromised due to a general lack of comparative data leading to a lack of integrated transdisciplinary research in this field (Kreutzmann 2001; Jianchu 2006; Tse-ring et al 2010). Research has largely been focussed on the impacts, rather than the drivers, of land use changes as well as the level of environmental consideration by people when engaging in land use change (Mottet et al 2006; Rudmann-Maurer 2008; Garcia-Martinez et al 2009; Osslon et al 2011; Bucala, 2014). Land use changes can be driven by a number of human and environmental factors (Bewket 2002) and studies often concentrated either on one driver of change, or on multiple but simplified drivers which led to over-simplified interpretations of the concept (Lambin et al 2001). It included either population change or climate change (e.g. Gentle and Maraseni 2012; Regos et al 2015) but not both of these factors.

The largest changes in land use experienced in mountain areas relate to the expansion and intensification of agriculture and well as deforestation (Zeleke and Hurni 2001; Sen et al 2002). In many areas the nature of agriculture also changed most noticeably from subsistence farming to economic (cash) crops or exotic medicinal plants (Sen et al 2002). Larger built-up areas correspond to a growing number of people living in the mountain areas (Tekle and Hedlund 2000; Bewket 2002). These human-induced changes are generally easier to determine since most human-induced change happen rapidly and over a short period of time whilst environmental drivers (e.g. climate change) induce change systematically and over much longer periods of time (Bewket 2002).

Studying the interaction between a single driver and land use change in isolation from other impacts was not possible because of the complexity of the system. Research simultaneously focussed on multiple, and varied, inputs into this dynamic system was required in order to better understand the changes that occurred.

The rate of urbanisation increased rapidly, especially in developing countries (Glaeser 2014) and consequently, urban expansion and the conversion of other land uses to built-up areas raised increasing concern (Breu et al 2005). Some research found decreased rural populations (Bucala 2014; Melendez-Pastor et al 2014; Regos et al 2015) whilst others found large increases in the number of people living on or near mountains. This indicates that there are other regional or local factors that influence whether or not populations on and around mountains increase faster or slower than the national population growth. In some areas, such as Ethiopia, the population increased by as much as factor of 4 between 1950 and 2000 and extensive increases in areas used for cultivation (Hurni et al 2005). Assessments of deforestation, reforestation and other land use changes had clear indications that changes in population size had a significant impact on land use (Hurni et al 2005). The influences of global trends, including access to global markets, have had an enormous impact even on rural communities in mountain areas (Jianchu et al 2006). These influences have been driving changes in societal perceptions, demands and priorities (Lambin et al 2001) which influenced what communities expect from the land. Societal development directly impacts on the extent and nature of land use changes (Mottet et al 2006; Olsson et al, 2011).

Compared to other biomes, the impacts and trends of climate change in mountain areas are not well known (Price 1995) although some progress in this regard has recently been made, especially for regions in the Alps and central Asia (Barry 2012). Changes in rainfall and temperature are key aspects to evaluate when investigating climate change in mountains (Espero´n-Rodrı´guez et al 2016). Recent studies, as explained by Barry (2012) and Grosjean (2001) focussed on indicators of climate change (e.g. snow lines). The socio-economic impact of climate change as well as appropriate mitigation and adaptation strategies and policies have all been central to many environmental research projects (e.g. Hannah et al 2005; Nogue´s-Bravo et al 2007; Salik and Ross 2009; Tse-ring et al 2010; Archie 2014; Schmitz et al 2015; Espero´n-Rodrı’guez et al 2016). Certain changes in climate change (decreased rainfall and increased mean temperatures) were linked to intensified socio-economic impacts. Climate change showed different trends in different areas indicating that, as with demographics, there are regional and local factors that influence climate change (Seleshi and Zanke 2004; Hurni et al 2005; Espero´n-Rodrı´guez et al 2016). This complexity of mountain climates highlights the importance of comprehensive understanding of these dynamic environments. Understanding climate change in mountain areas is important; especially in terms of its impact on people and consequently, land use (Price 1995; Debarbieux and Price 2011). Climate change had a major influence on land use along with drivers such as changes in human population (Gentle and Maraseni 2012).

Interest in the sustainable development of mountain areas has increased prompting research into the impacts of climate change, and other variables, in these complex ecosystems (Price 1995; Breu et al 2005; Jianchu et al 2006; Debarbieux and Price 2011). There are mixed findings and much uncertainty with regards to the main drivers of human-induced land use change in mountain areas (Tavor et al 2013; Regos et al 2015) and so; to contribute to the understanding of human-induced land use change in mountain areas; we evaluated changes in the population as well as the climate as potential drivers of land use change in South African mountain areas. The study focussed on population size and climate as drivers of land use change rather than the impact of climate change on population.

Objectives of this project

The aim of this project has been to identify the dominant driving force(s) that bring about change in human use of the mountain foothills. We used data covering a period of approximately 30 years (1985-2015). The factors investigated were human demographic change and climate change.

In order to achieve this, we defined the following objectives:

- Determine demographic changes including the number of people, population density, and employment status and age distribution over the study period.
- Quantify and evaluate the changes in land use over the study period.
- Determine climatic trends in temperature and rainfall for the study period.
- Evaluate whether climate, demographic or socio-economic changes best explain the land use changes.

Methods

Study Areas

Two sites were identified using the following criteria:

- The site must form part of the Drakensberg Escarpment with an adjacent human community that is dependent on resources from the mountain for their livelihood.
- Comparable and/or similar demographic and climatic data must be available for both sites.

We selected study areas by excluding areas where the inhabitants were not highly dependent on the mountain. For example, sites featuring commercial farming with irrigation from boreholes were excluded as potential study areas.

Mariepskop. This site is part of the northern Drakensberg Mountains, with communities or settlements to both the north and south of Mariepskop. This part of the mountain forms part of the Molatse Canyon provincial nature reserve. The study area is 1 496 km^2 (149 600 ha) in size (Figure 1).

Thukela. This site borders on Lesotho and is located in the central Drakensberg with settlements scattered throughout the landscape. There are formally and informally protected areas, including the Royal Natal National Park. The site comprises an area of 520 km^2 (52 000 ha) in size (Figure 1).

Geographical and land use data

The geographical data included administrative boundaries, rivers and other water bodies, roads, railways and protected areas (SANSA, 2009) provided an appropriate spatial mapping context.

We mapped two sets of land use cover, per study area, directly from high resolution greyscale aerial photographs of Mariepskop (1974) and Thukela (1980) and also from high resolution greyscale imagery captured during 2011-2012 (Chief-Surveyor General, Pretoria, South Africa). We defined the following land use categories (Fig. 2):

1. **Settlement** areas - unplanned residential development on large plots where the dwelling constitutes a small portion of the total plot size.
2. **Cultivated land** - land used for the commercial agriculture.
3. **Plantations** - commercial plantations including fields that were cleared at the time because of plantation rotations.
4. **Subsistence farming** - unorganised and small cultivated fields.
5. **Town development** - planned residential development areas with structured road networks and other formal developments such as schools and hospitals.

Images were geo-rectified and the boundaries of land use units were digitised. ESRI Connect (from ESRI, Redlands, California) was used to assist in the classification of an area in the event that it was unclear on the source image. The total coverage (ha) of each category was calculated using ArcMap (from ESRI, Redlands, California). Coverage/cover refers to the extent of a specific land use category.

Demographic data

South African census raw data for 1996, 2001 and 2011 (StatsSA, 1996, 2001, 2011) were used along with mid-year population estimates released by Statistics South Africa (StatsSA, 2005, 2010, 2015). Census data prior to 1996 were available only in the form of a national sample; not suitable for inclusion in this study. The administrative boundaries in the study areas were different for each census year; hence we considered tendencies in the demographics rather than using data counts. Data were sourced according to the lowest level of administrative census boundary (enumeration areas). The following variables were evaluated:

- Population size.
- Household size.
- Population distribution by age.
- Population density (calculated using the number of people and the area within the administrative boundaries used).
- Employment status.
- Migration between provinces.
- Population growth.
- Level of education (Gr 12 and higher)

Demographic analysis was also done for Mbombela, Mooirivier, Phalaborwa, Pietermaritzburg and Ladysmith, as well as Gauteng, in order to compare the population distributions and growth from the study areas within a regional and national context. We used a G-test to evaluate the significance of change in population distribution over time as well as the significance of differences in population distribution between study areas and economic centres. G-tests were useful as a likelihood ratio statistic because we had a very large sample group and were testing a single nominal variable (people) with multiple values (age groups) (Sokal and Rohlf, 1968). Demographic data were not available as individual records which limited our choice of statistics to use.

The national electricity utility, Eskom, compiled a dataset of points, representing physical building structures, from SPOT 5 imagery. Each structure was classified according to predefined categories (e.g. dwelling, mines). Mapping was done by image interpretation, i.e. no field work, and where cadastral data exist, one dwelling per cadastral polygon. In rural areas, each building structure is mapped. The Eskom building count data set (Eskom, 2006, 2011) was used to quantify the number of dwellings. Only points classified as "dwelling" and located within defined land use categories were used. Building counts give a good indication of population size (assuming a constant household size) and may be a more accurate population estimate in rural areas than census data. The coverage (ha) of each land use category and the number of dwellings (Eskom, 2006, 2011) per land use category were used to calculate the dwelling density per land use (Table 2).

Climate data

Unpublished weather data from the South African Weather Services (WeatherSA, 2015) were used. The following criteria were considered when selecting weather stations from which to source data:

- Proximity to either of the study areas
- Elevation
- Completeness of data series
- Continuum of records over a prolonged period of time

Records from Mariepskop, Hebron and Salique were used for the Mariepskop site while Cavern Guest Farm, Royal Natal National Park, Shaleburn and Witsieshoek records were sourced for Thukela (Table 1). Although the Shaleburn station is far from the study area, it was included because of its comparable high altitude and due to lack of sufficient temperature data from Witsieshoek and Cavern Guest Farm. The data consisted of recordings of the daily minimum and maximum temperatures and/or daily rainfall for each station. Average temperature was defined as the mid-point between the maximum and minimum temperatures. June, July and August represents winter and December, January and Febuary; summer. Statistical significance testing was done to assist in the interpretation of the data. We used a Generalised Least Squares (gls) regression model to do the statistical significance testing.

The following variables were used:

- Number of winter days with a minimum temperature of 0^{o}C or less.
- Average, minimum and maximum temperature for winter.
- Average, minimum and maximum temperature for summer.
- Number of rainfall days per year.
- Total rainfall per year.

Results

Land use

Settlement areas increased by 96% at the Mariepskop study area and town development increased in coverage from being completely absent in 1974, to 1 775 ha in 2013. Subsistence farming (16%) and cultivated land (52%) had lower increases than town development and settlement areas. Plantation was the only land use that decreased in coverage at Mariepskop. (Figure 3 and Table 2).

For the Thukela study area, settlement (77%) and town development (90%) were also the land use categories with the largest increase in coverage over the study period. Coverage decreased for cultivated land (72%) and plantation (40%) whilst subsistence farming remained unchanged (Table 2).

Demography

The census population count data for the two study areas proved not to be a reliable indicator since administrative boundaries were different from one census to the next; hence we decided to rather use population *density* as indicator. Even then the results were inconsistent, probably due to significant undercounts in the national census initiatives (Table 3). We decided to rather use Eskom's building count data as a population density indicator. At Mariepskop, the dwelling counts within all land use categories (except plantations) increased at mean annual rates for settlement (1%); for town development (0.4%) for cultivated land (81.1%) and subsistence farming (1.4%). Thukela had no change in the number of dwellings for the cultivated land and plantations categories. The other categories increased with a mean annual rate of settlement (4%), town development (12%) and subsistence farming (4.4%). The building counts for urban areas as well as subsistence farming increased; and dwelling counts in plantation areas decreased; in both study areas (Table 2). The density of dwelling for settlement and town development areas for the Thukela study area decreased. All other dwelling densities (for both study areas) increased (Table 2).

South Africa has a relatively young population with a median age between 22 and 25 years (StatsSA, 2015). The age distributions of the populations in the two study areas over the period 1996 to 2011, had a decrease in the percentage of the population represented by children (aged 0-9 years decreased around 2.5%) and teenagers (aged 10-19 years decreased around 3.5%) but a slightly increased percentage of young adults (aged 20-29 years increased around 0.7%). The nearby economic centres of Mbombela (Figure 4) and Phalaborwa as well as Mooirivier (Figure 4), Ladismith and Pietermaritzburg had population distributions where young adults were the single largest group of people. The Gauteng population distribution had the smallest percentage of the population younger than 20 years and the largest percentage of the population from 20-40 years (Figure 4). Although the population distribution in Gauteng from 1996 to 2011 appear very similar, the province's population is very large; hence even a small change in the percentage of the population distribution represents a large number of people. The population count for Gauteng indicated that the number of young adults in the province nearly doubled from 1996 to 2011. The number of children (0-9 years) in Gauteng were also nearly double in 2011 when compared to the 1996 population count. The results obtained from G-tests indicated that Mooirivier, Mbombela and Gauteng had a significant increase in young adults from 1996 to 2011 whilst the study areas had a significant decrease in young adults from 1996 to 2011. Based on 2011 data, the age distribution between each study area and the nearby economic centre were significantly ($p<0.0001$) different from each other, especially for the young adults age group, and so was Gauteng, when compared to the national population distribution.

Both study areas as well as all the regional economic centres (Mbombela, Mooirivier) had a decrease in the percentage of the population represented by young children and teenagers and increased percentage of the population in older people (50+) from 1996 to 2011. This trend was also evident for Gauteng, specifically for people 50 years and older (Figure 4). The 2001 population distributions for the economic centres had a mixture of trends. However, when we compared the 1996 and 2011 data, these centres also had a decreased percentage of the population represented by people younger than 20 years over the study period. From 1996 to 2011, both the 50-59 years and 60-69 years age groups represented an increased percentage of the population of the economic centres. Both the study areas as well as the economic centres and Gauteng all had a decrease in the percentage of children (0-9 years) and teenagers (10-19 years) between 1996 and 2011. Gauteng had a mean annual population growth of 3.6% which is much more than both the World Bank Group national estimation of 1.6% and Statistics South Africa estimates, 2001-2016, of 1.65% (StatsSA, 2015). Mbombela (2.4%) and Mooirivier (2.9%) also had growth rates higher than the national estimates. In comparison, the two study areas experienced much lower mean annual growth rates; Mariepskop (-1.1%) and Thukela (1.7%). Migration data indicated that an overall total of 3.45% of the Limpopo and Mpumalanga provinces' and 1.35% of the Kwa-Zulu Natal province's population migrated to Gauteng during the period 2001-2016 (Table 3). That is an estimated 1 392 298 people for the period 2001-2016; a mean of 92 819 people per year moving to Gauteng from only these provinces.

The percentage of the population of the study areas that are formally employed increased from 1996 to 2011 by 12.16% (Mariepskop) and 13.31% (Thukela) respectively while those without any income decreased by 19.9% (Mariepskop) and 7.03% (Thukela) (Table 3). However, both the study areas had an increase in the percentage of population without income from 2001 to 2011 (Table 3). The changes at Mariepskop were much more drastic than at Thukela. The level of education has generally improved a lot in both study areas. The percentage of people who have a Gr 12 level of education increased in both study areas between 2001 and 2011. Despite this, both study areas scored below the national average (28.9% for 2011). Gauteng exceeded the national average in all three census years and had a 12% increase in Gr 12 education level from 1996 to 2011. Both study areas experienced a decrease in the percentage of people who have an education higher than Gr 12 however the figures increased for Gauteng (9.9% to 17.7%) and nationally (7.1% to 11.8%) between 1996 and 2011.

Climate

None of the weather stations for Thukela had significant trends for mean annual rainfall (Table 1). The data recorded at Royal Natal National Park prior to its conversion from manual to electronic, showed no change in the annual number of rainfall days (Figure 5). Including the data recorded after the station's conversion showed an overall trend of increasing annual rainfall days (approximately 30 days over the data series). Shaleburn has many more rainy days per year than any of the other stations so the inclusion of this short data series (Table 1) in the combined result for Thukela would have resulted in a misrepresentation of the mean annual number rainfall days for the study area. Cavern Guest Farm (1490m altitude) and Witsieshoek (1699m altitude) had increasing number of rainfall days whilst Royal Natal National Park (1392m altitude) and Shaleburn (1609m altitude) had a decreasing number rainfall days but none of these changes were significant. Royal Natal had a decrease in mean annual rainfall whilst the other three stations in the Thukela study area had an increased mean annual rainfall. Again, none of these changes were significant. The data from Witsieshoek skewed the combined results for Thukela as the mean annual rainfall at this station is much less due to the fact that it is situated within the rain shadow. Witsieshoek and Royal Natal had the longest data series with Shaleburn and Cavern Guest Farm both having shorter, more recent series (Table 1). Witsieshoek data were excluded for this calculation as its inclusion would make it appear as though the site experienced an increase in annual rainfall despite all stations experiencing almost no change in annual rainfall. For both sites we found decreased (approximately 200 mm over the entire data series) in terms of the mean annual rainfall (Figure 5) but the over-all results for both study areas were insignificant (Table 1).

The weather stations used for Mariepskop had similar patterns therefore we decided to combine the results from all the stations for the purpose of plotting graphs as this would not skew the data. The combined results for Mariepskop indicated a decrease over the study period in the annual number of rainfall days (from about 100 to 60 days) (Figure 5) however, only the changes at Hebron were significant (gls test, $p<0.005$) (Table 1). The mean annual rainfall also decreased between 1996 and 2011 (Figure 5). The decreased rainfall at Hebron and Mariepskop weather stations were not significant and results for Salique indicated an increase in annual rainfall, which was also not significant (Table 1).

For the Thukela site, temperature data from only the Royal Natal National Park and Shaleburn weather stations were usable. The other weather stations either had no or very incomplete temperature data. A sudden change in the mean winter temperatures for Royal Natal National Park, from 2007 onwards, raised questions in terms of the accuracy of data recorded before and after the automation of the station. Without other high-altitude weather station data recorded within close proximity of Royal Natal National Park, it was difficult to validate the results from this station. We therefore decided to consider the data (before or after automation) as separate data series. There was a difference of almost 1°C in the mean minimum temperatures recorded at Royal Natal National Park for the years before and after the station was changed from a manual to an electronic weather station. Only data from 2007 onwards were included along with the data from Shaleburn. Winter minimum temperatures at Royal Natal (Figure 5) decreased significantly (gls test, $p<0.005$) between 1996 and 2011 whilst the changes in maximum summer temperatures, although decreasing over this period were, not significant (Table 1). Shaleburn had a significant (gls test, $p<0.005$) increase in mean summer maximum temperature. It also had decreased mean winter minimum temperatures but this change was not significant.

At Vaalhoek weather station, there was an increase in both the mean summer maximum temperature and mean winter minimum temperature but only the increase in mean winter minimum temperature was significant (gls test $p<0.005$) (Table 1).

Discussion

Climate change was not an important driver of land use change

The toughest challenge in terms of evaluating climate change was the lack of available long term data (particularly for the Thukela study area) as trends in climate are difficult to detect from data series only spanning 20-30 years. However, if strong climate change did occur, this would be evident from data series in the order of 30 years such as those that we used.

If climate change was a main driver of land use change, subsistence farming and cultivated land would have been most affected. However, these two land use categories did not have the largest changes at either of the study areas, being relatively stable with respect to land use surface area. At Mariepskop there was a significant expansion of commercial cultivated land to the north, outside of the subsistence farming area. However, overall, change in agricultural land use was not the most important feature of this landscape at all (Table 2).

In addition, if climate change was important, we would expect consistent evidence from most (or all) weather stations of extended periods of drought, increasingly inconsistent rainfall or a significant change in temperature (especially minimum winter and maximum summer temperatures) as well as annual rainfall. There were no significant changes in annual rainfall at any of the weather stations. In terms of the number of rainfall days per year, only Hebron had a significant change (a decrease). Shaleburn and Vaalhoek had significant changes in summer maximum temperature and winter minimum temperature respectively. All other changes were not significant.

The changes in climate at the various stations were very different at weather stations, even within the same study areas. The lack of any systematic change among the weather stations with interpretable data sets leads to the conclusion that there has not been a significant and systematic change in climate among the variables investigated. It is therefore unlikely that climate brought about the changes in land use in the two study areas.

Increased population size did not drive land use changes

Although South Africa has ample demographic data available, the total population counts for the two study areas appear unreliable. Fortunately, alternative data such as the Eskom dwelling counts were available to collaborate findings.

The economic centres of Gauteng, Mbombela and Mooirivier had much higher population growth rates than the study areas and the national estimates. Gauteng, in particular, experienced large-scale immigration, especially from neighbouring provinces during the past 15 years. This, along with natural population growth, has led to Gauteng's population growth rates that far exceed the national population growth rate. A lower population growth rate of at the study areas (1% per annum at Mariepskop and 1.7% at Thukhela, compared to rates around 2.5% in the regional centres and around 3.6% in Gauteng) appears to result from a decreased percentage of young adults (most likely age group to give birth) resulting in growth rates (Table 2) lower than the national estimates.

Population age distribution for the study areas, nearby economic centres as well as Gauteng indicated a decrease in the 0-9 years and 10-19 years age groups and slight increases in age groups of 50+ years, suggesting that the population started aging very slowly, consistent with the population forecasts of the World Bank Group (2016) and South Africa's national mean household size that decreased from 4.4 people to 3.4 people between 1996 and 2011 (StatsSA, 1996 and 2011). The proportion and number of young adults (20-29 years) in Gauteng (23.3%) was greater than the national (20.2%) figure. The decreased percentage of young adults in the rural study areas, contrary to the national trend, could be attributed to migration of young adults into metropolitan areas in search of opportunities and access to services.

Migration statistics indicated people are moving away from rural areas to larger towns and cities. Provincial migration estimates indicate that between 2001 and 2016 Gauteng has the greatest net immigration rate of 1 474 354 people (11.2% of provincial population) (StatsSA, 2015). Areas from which people migrate would generally be characterised by low levels of formal economic activity, limited provision of services or provision of only select services, as well as geographic isolation from major economic centres or access to centres of economic growth. The migration trends identified in the Statistics South Africa mid-year population reports support the changes in population distributions we found for the study areas as well as surrounding economic centres. The migration, to Gauteng, from Kwa-Zulu Natal (including the Thukela study area) is less than that of Mpumalanga and Limpopo. Durban, one of the largest cities in South Africa, is a metropolitan area in Kwa-Zulu Natal which could account for fewer people leaving the province in search of opportunities. Neither Limpopo nor Mpumalanga have a metropolitan area within their provincial boundaries. Gauteng would be an attractive migration option as Limpopo and Mpumalanga are neighbouring provinces to Gauteng.

In addition, notable demographic changes were in relation to employment and household income. The Thukela study area had a large decrease in the percentage of households without formal income. For the Mariepskop study area, this variable was almost unchanged but both study areas had a big increase in the percentage of people who are formally employed (Table 3). Statistics of formal income may be influenced by the allocation of social grants to the poor, a system implemented by national government after 1994. Increased percentages of people employed is indicative of the changes in the economic structure of the study areas, tending towards a more formal economy, a trend supported by the changes in land use.

Land use change largely reflected increased urbanisation

Changes in land use tend towards increasing urbanisation while the extent of subsistence farming (an indication of direct dependence on mountain resources) remains almost unchanged (Table 2). An increased number of households and dwellings within the study areas, particularly within the urban areas is evidence of urbanisation.

Unlike findings from Europe (e.g. Mottet et al, 2006; Tasser et al, 2007) and other research in Africa (Zeleke and Hunri, 2001), we did not find a large decline in small-scale agriculture (subsistence farming), especially at the Thukela site. Although subsistence farming had very little change in land coverage, the increase in dwelling density may be indicative of a growing number of households dependent on subsistence farming (Table 2). This may also indicate that households participate in both subsistence farming and formal economic activities.

Plantation coverage decreased, particularly in Mariepskop as a result of the collapse of the forestry industry in the region that employed many people. A large-scale reduction in plantation-related employment could be one of the reasons that more households may be dependent on subsistence farming. In return, an increase number households that are dependent on the same land could also force people to complement subsistence farming with additional income through formal employment or to move to one of the metropolitan areas.

The Thukela study area had a slower rate of land use change when compared to Mariepskop study area. Extensive protected areas, eco-tourism and nature-based tourist operations and developments in Thukela probably influenced the extent and rate of land use change in this area: land use change would be less likely to occur as the natural state of the environment is essential to this income-producing industry in the area.

Socio-economic factors drive land use change

There is no convincing evidence that suggests that there were significant changes in climate at either of the study areas and hence we conclude that land use change was not primarily as a result of climate change. Although there were many notable demographic changes, when considered collectively, it is clear that the population growth was not a main driver of land use change. Contrary to many studies (e.g. Mottet et al, 2006; Tasser et al, 2007), we did not find the conversion of subsistence farming to commercially cultivated land. Urban areas are expanding significantly. The decrease in the percentage of people with higher education (beyond Gr 12) is well supported by the migration trends we found. Young adults are leaving the study areas, once they have completed secondary school, in order to search for further educational or career opportunities. It is also an indication that those young adults who leave the study areas for further education generally do not return to live there. The improved level of education in terms of Gr 12 supports the conclusion that the community is more exposed to the global market and would naturally strive towards a more formal economy (to earn money), and progressively move away from a lifestyle reliant on subsistence alone. Based on the evidence gathered during this project, we conclude that neither climate change nor demographic change were the primary drivers of land use change. Land use change was driven by socio-economic factor associated with increased secondary education, increased employment, increased permanent income and increased urbanisation

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Data Sets and other Sources

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2. Eskom; Eskom National Building Count dataset. 2006. *Points layer data for building structures which were mapped using the SPOT 5 National Mosaic.*
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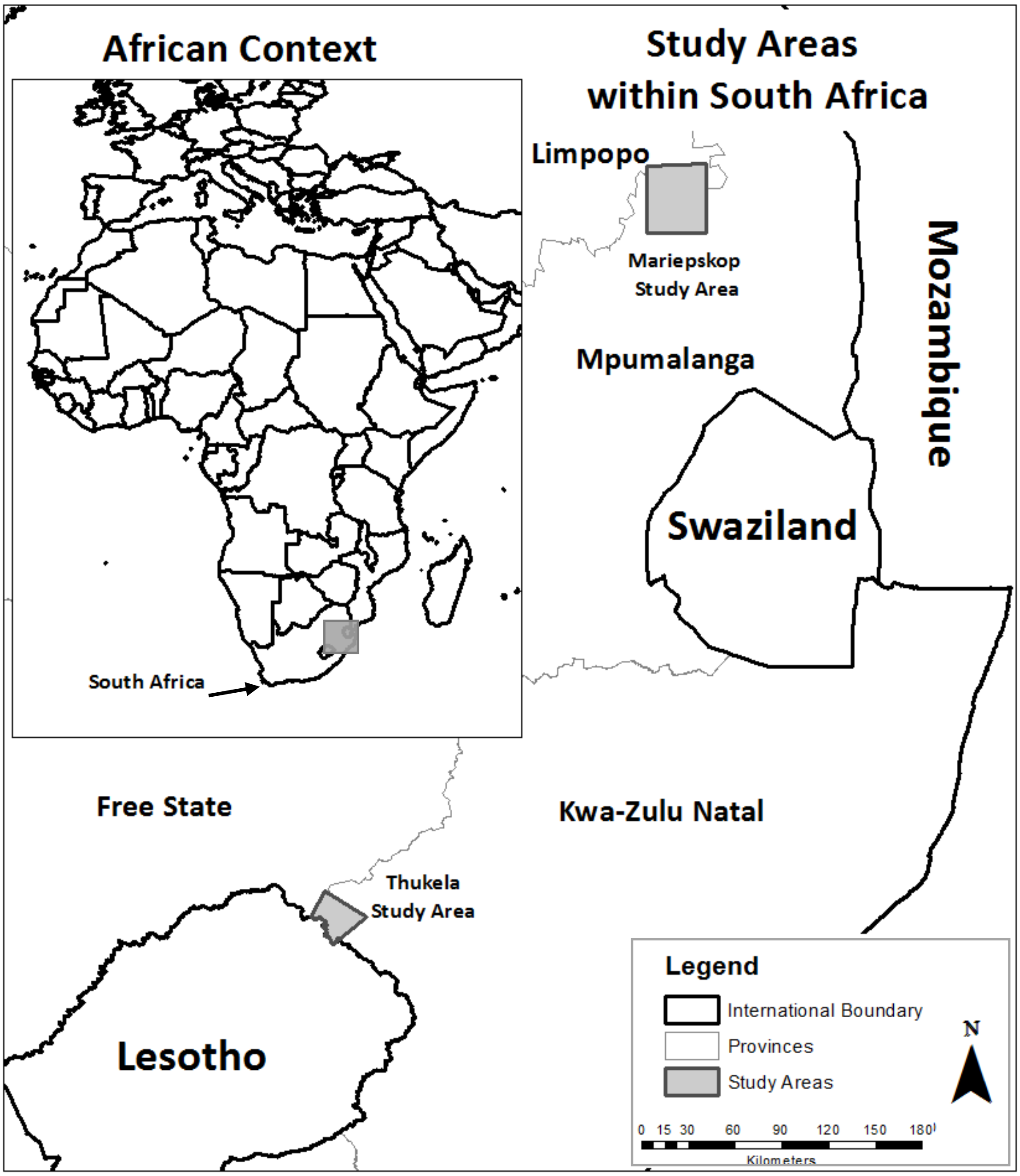
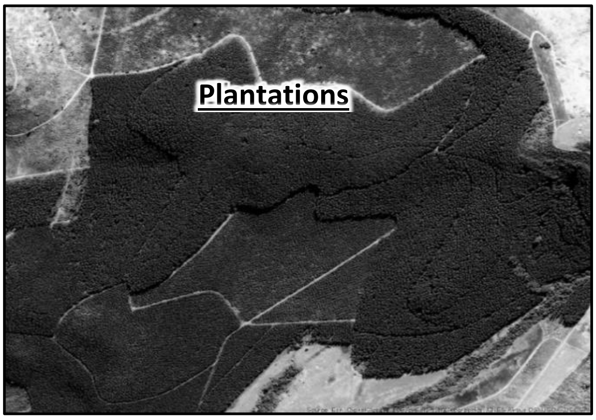


Figure 1. Location of the two study areas within South Africa and Africa. The extent of the Mariepskop study area is 1 496 km^2 and the Thukela site is 520 km^2

a). Example of Town Development Land use.

b). Example of Settlement Land use.

c). Example of Cultivated Land use.



d). Example of Plantations Land use.

e). Example of Subsistence Farming Land use.

Figure 2. Examples the 5 land use categories defined for this project. These examples are from within the study areas. The imagery is the same as what was used for mapping of the 2013 land use areas.

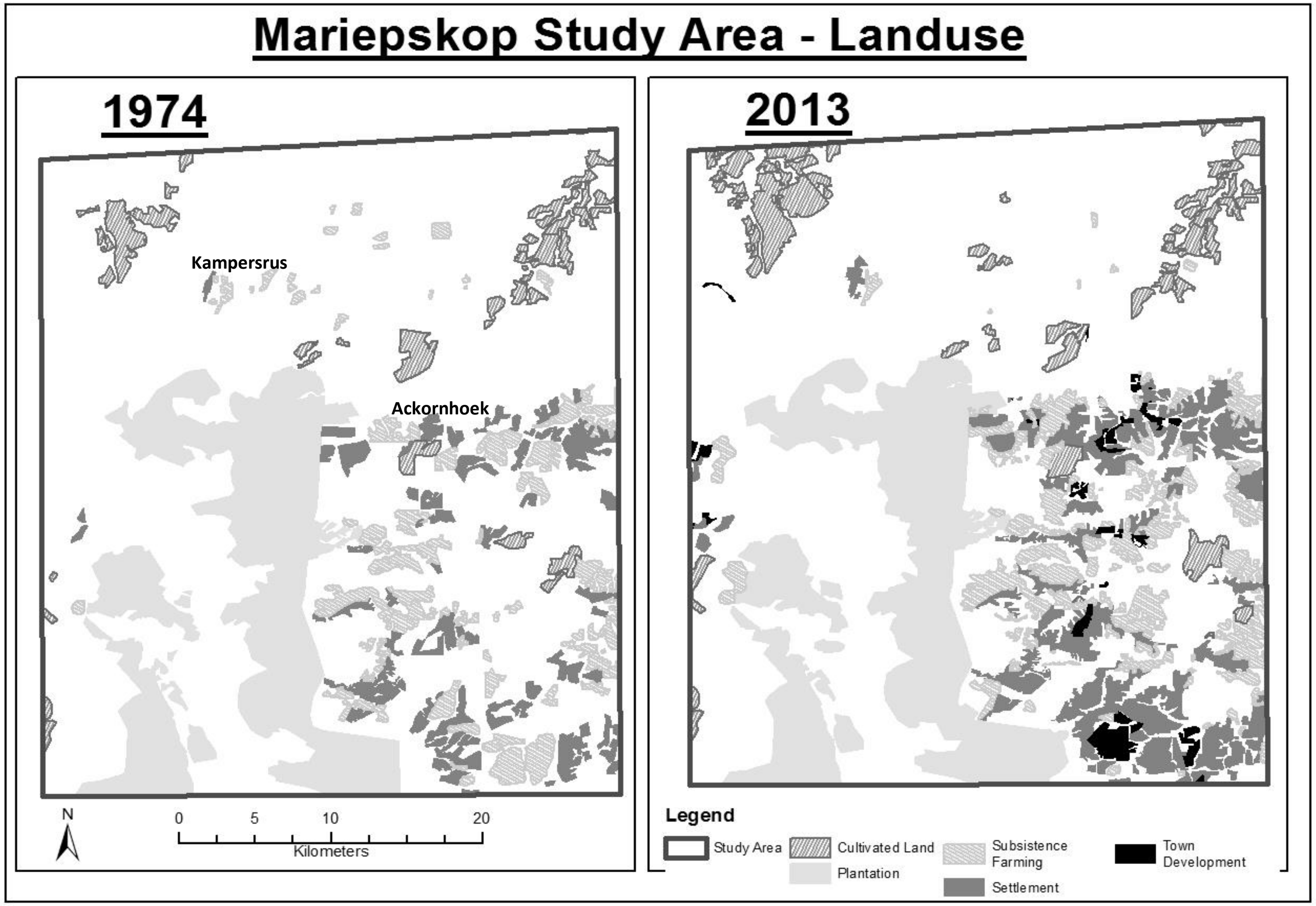


Figure 3. Map showing the coverage at the Mariepskop site of the five land use categories as it was in 1974 and in 2013. Town Development was completely absent in 1974. The majority of the changes in land use, according to the categories defined for this project, were concentrated within the bottom right quarter of the study area map.

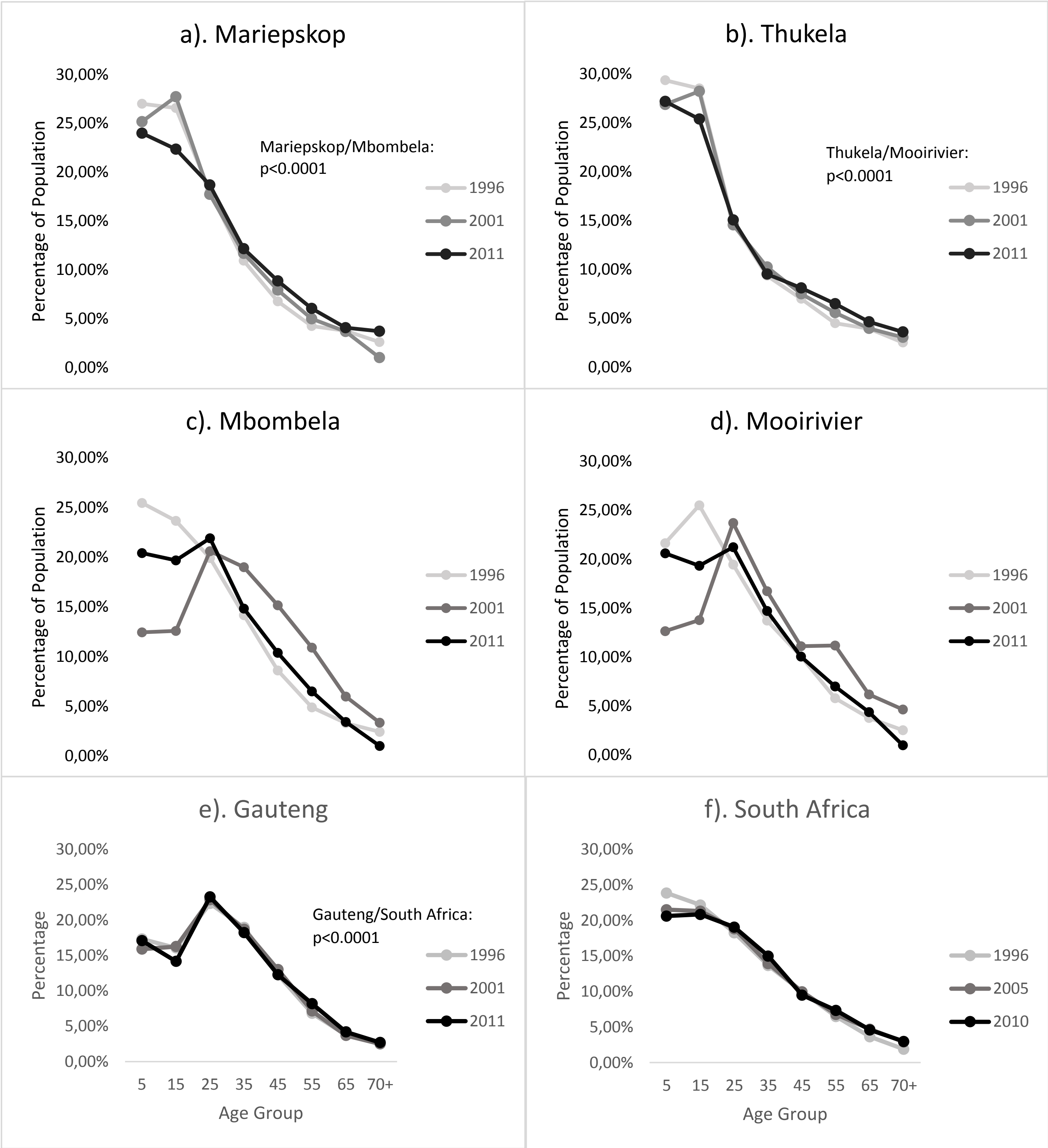


Figure 4. Population distribution by age for the Thukela and Mariepskop study areas as well as three urban centres: Mooirivier, Mbombela (each located nearby a study area) and the large metropolitan hub of Gauteng (StatsSA, 1996, 2001, 2011) and national population projections (World Bank data for 1996, StatsSA data for 2005 and 2010). Each x-axis value indicates the mid-point of a 10-year age group represented (e.g. 15 refers to age group 10-19). Both of the study areas, the economic centres and the national population had significant (p<0.0001) changes in population age distribution from 1996 to 2011 .

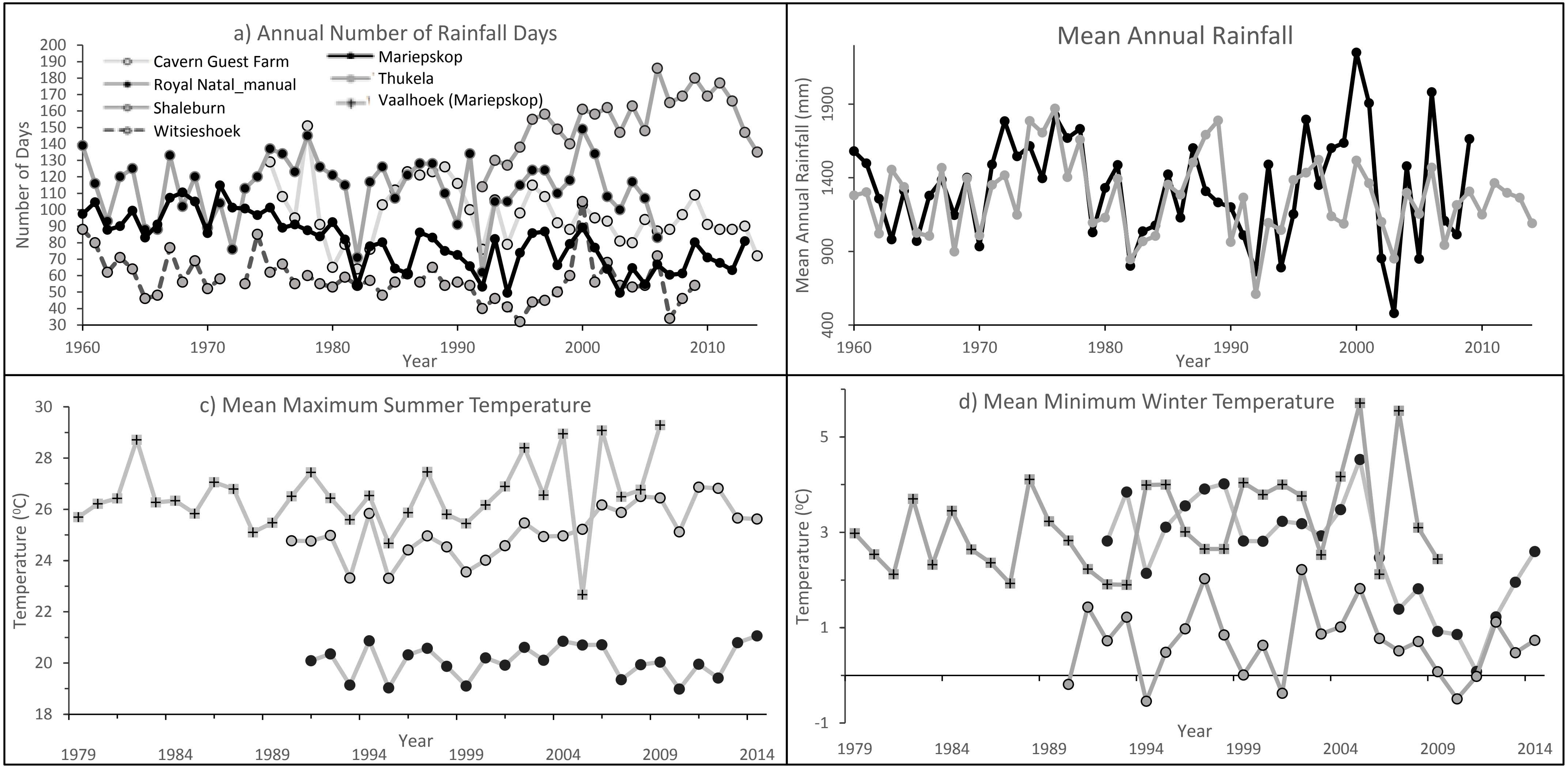


Figure 5. a) The annual number of rainfall days for Mariepskop (all weather stations combined), as well as each of the weather stations for Thukela. Only manually recorded data from Royal Natal National Park is shown WeatherSA, 2015). b) Mean annual rainfall calculated as the mean rainfall of all the stations used for each study area. The changes recorded at the two study areas are definitely comparable (WeatherSA, 2015). c) Mean maximum summer temperature and d) mean minimum winter temperatures as calculated using raw data (from weather stations) sourced from the SA Weather Services (WeatherSA, 2015). The months of December, January and February denote summer and June, July and August were denoted as winter.

Table 1. Data sets, and the weather stations from which the data were obtained (WeatherSA, 2015). Statistical significance (from generalised least squares regression) indicated by: * for p<0.05; ** for p <0.01; *** for p<0.005

Study Area	Station	Latitude	Longitude	Elevation (m)	Temperature t-value		Rainfall t-value	Rainy Days t-value	Data series length	Distance from study area
					Max	Min				
Thukela	Cavern Guest Farm	28.6360 S	28.9610 E	1490			0.249	-1.647	1975-2014	Within site boundaries
	Witsieshoek	28.5330 S	28.7950 E	1699			0.824	-1.36	1960-2010	20 km
	Royal Natal National Park	28.6850 S	28.9540 E	1392	0.498	-2.074	-0.273	-0.125	1960-2014 (rainfall) 1991-2014 (temperature)	Within site boundaries
	Shaleburn	29.7860 S	29.3520 E	1609	***5.723	-0.437	0.248	1.403	1992-2014	100 km
Mariepskop	Mariepskop	24.5790 S	30.8700 E	914			-0.814	-0.477	1960-2014	Within site boundaries
	Hebron	24.6670 S	30.9330 E	1065			-0.073	***-3.756	1960-2014	Within site boundaries
	Salique	24.6000 S	30.9000 E	808			0.524	-1.706	1960-2014	Within site boundaries
	Vaalhoek	24.7330 S	30.7830 E	1158	1.372	*** 3.554			1978-2013	2.4 km

Table 2. Surface area covered by each land use category in the two study areas. Eskom Dwelling Counts (Eskom, 2006, 2011) were used to calculate the number of dwellings and therefore the density of dellings in each land use category. Since 2006 is much closer to 2013, both sets of dwelling counts (2006 and 2011) were evaluated based on the 2013 land use coverage.

Study Area	Land use category	Size (ha)		Total change in size	Dwellings per land use category		Mean change in number of dwellings per year	Density: dwellings/km^2		
	Year	**1986**	**2013**	**Ha (%)**	**2006**	**2011**	**2006-2011 (%)**	**2006**	**2011**	**2006-2011 (%)**
Thukela	Settlement	658	1 165	507 (77)	1 700	2 021	64,20 (4)	2,58	1,73 %	-0,85 (32.8)
	Town development	63	120	57 (90.4)	161	258	19,40 (12)	2,56	2,15	-0,41 (15.8)
	Cultivated land	341	95	-246 (-27.8)	0	0	0,00	0,00	0,00	0,00
	Plantation	68	27	-41 (-39.7)	2	2	0,00	0,03	0,07	0,04 (151.8)
	Subsistence farming	5 482	5 471	-11 (0)	1 009	1 231	44,40 (4.4)	0,18	0,23	0,04 (22.2)
Total					2 872	3 512				
	Year	**1974**	**2013**		**2006**	**2011**	**2006-2011 (%)**	**2006**	**2011**	**2006-2011 (%)**
Mariepskop	Settlement	6 329	12 380	6 051 (95.6)	40 907	43 106	439,80 (1)	3,30	3,48	0,18 (5.3)
	Town development	0	1 775		9 550	9 759	41,80 (0.4)	5,38	5,50	0,12 (2.9)
	Cultivated land	4 402	6 685	2 283 (51.8)	104	526	84,40 (81.1)	0,02	0,08	0,06 (405.7)
	Plantation	10 962	7 339	-3 623 (-66.9)	679	675	-0,80 (-0.1)	0,09	0,09	0,00
	Subsistence farming	7 284	8 445	1 161 (15.9)	2 528	2 703	35,00 (1.4)	0,30	0,32	0,02 (6.9)
Total					53 768	56 769				

Table 3. Census data for the two study areas (StatsSA, 1996, 2001, 2011) showing the key population parameters evaluated in the study, including the percentage of people that have completed secondary education (Grade 12) and those with formal tertiary education.

Study Area	Year	Population Size (no. of people)	Density (people per km^2)	Population with no income (%)	Persons employed (%)	Education (%)		Number of People in Province Migrated to Gauteng	% of Provincial Population Migrated to Gauteng
						Gr12	Tertiary		
Thukela	1996	22 334	42,95	3 207 (14.36)	6,67	No data		No data	No data
	2001	53 474	29,21	2 820 (5.27)	16,71	3.60	1.55	274 630 (2001-2011)	1.35 (2001-2011)
	2011	12 808	24,63	939 (7.33)	19,98	63.95	0.92	148 197 (2011-2016)	1,36 (2011-2016)
Mariepskop	1996	41 379	27,66	17 489 (42.27)	16,56	No data		No data	No data
	2001	245 124	41,10	23 866 (9.74)	23,79	10.46	5.71	632 212 (2001-2011)	3,45 (2001-2011)
	2011	41 379	19,64	9 253 (22.36)	28,72	41.20	3.25	337 253 (2011-2016)	3,29 (2011-2016)